European Journal of Trauma and Emergency Surgery (2018) 44 (Suppl 1):S3–S271
https://doi.org/10.1007/s00068-018-0922-y

GUIDELINE

Level 3 guideline on the treatment of patients with severe/multiple injuries

AWMF Register-Nr. 012/019

Polytrauma Guideline Update Group

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Spering, Dr. med. Christopher	-	2.2, 2.3
Stengel, Prof. Dr. med. Dirk	3.3, 3.4	3.3, 3.4
Stolpe, Dr. med. Erwin	1.4	-
Strasser, Prof. Dr. med. Erwin	-	2.16
Sturm, Prof. Dr. med. Johannes	1.4	-
Stürmer, Prof. Dr. med. Klaus Michael	2.2	-
Swoboda, Prof. Dr. med. Lothar	3.2	-
Täger, Prof. Dr. med. Georg	2.10	-
Tjardes, Dr. med. Thorsten	3.10	-
Trentzsch, Dr. med. Heiko	-	***1.1***, 1.2, 1.4, 2.15

Authors/Coauthors	First Version 2011	Update 2016
Türkeri, Levent	1.8, 2.8, 3.6	-
Voggenreiter, Prof. Dr. med. Gregor	2.4	-
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Wafaisade, PD Dr. med. Arasch	-	2.16
Wagner, Dr. med. Frithjof	-	1.5, 2.6, 3.5
Walcher, PD Dr. med. Felix	1.4	-
Waldfahrer, Dr. med. Frank	2.14, 3.13	***2.14***, ***3.13***
Waydhas, Prof. Dr. med. Christian	1.1, 1.2, 1.4	***1.1***, 1.2, ***1.4***
Weinlich, Dr. med. Michael	1.4	-
Wessel, Prof. Dr. med. Lucas	-	2.5, 2.17, 2.18, 3.4
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Wölfl, Dr. med. Christoph Georg	1.4	1.9
Woltmann, Prof. Dr. med. Alexander	2.9, 3.7	2.9, 3.7
Wurmb, Prof. Dr. med. Thomas	-	1.2, 1.10, 2.6, 2.18, 3.5
Yücel, Dr. med. Nedim	3.10	-
Zimmermann, Prof. Dr. med. Gerald	1.4	-
Zwipp, Prof. Dr. med. Hans	1.9, 2.12, 3.11	-

*The chapters marked in ***bold*** were chiefly coordinated for update by the corresponding author

Contents

List of Tables

The evidence tables to this guideline can be found in the guideline report available at: http://www.awmf.org/leitlinien/detail/ll/012-019.html

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List of Abbreviations

A.	Artery
AAST	American Association for the Surgery of Trauma
ABC	Assessment of blood consumption
ABCD	Airway/Breathing/Circulation/Disability
ACS COT	American College of Surgeons Committee on Trauma
ACTH	Adrenocorticotropic Hormone
ÄZQ	German Agency for Quality in Medicine (*Ärztliches Zentrum für Qualität in der Medizin*)
AIS	Abbreviated Injury Scale
ACS	Abdominal Compartment Syndrome
ALI	Acute Lung Injury
ALS	Advanced Life Support
AP	Apheresis Platelets
a.p.	anterior-posterior
aPTT	activated Partial Thromboplastin Time
ArbStättV	Workplace Ordinance (*Arbeitsstättenverordnung*)
ARDS	Acute Respiratory Distress Syndrome
ASIA-IMSOP	American Spinal Injury Association – International Medical Society of Paraplegia
ASR	Workplace Guideline (*Arbeitsstätten-Richtlinie*)
ASA	Acetylsalicylic Acid (aspirin)
AT	Antithrombin
ATLS®	Advanced Trauma Life Support
AUC	Area under the curve
AWMF	Association of Scientific Medical Societies in Germany (*Arbeitsgemeinschaft der Wissenschaftlichen Medizinischen Fachgesellschaften*)
BÄK	German Medical Association (*Bundesärztekammer*)
BE	Base Excess
BGA	Blood Gas Analysis
BLS	Basic Life Support
BSA	Body Surface Area
BW	Body Weight
C1-7	Cervical Spine Vertebrae
Ca^{++}	Calcium
CCT	Cranial Computed Tomography
CEBM	Oxford Centre for Evidenced Based Medicine
CI	Confidence Interval
CK-MB	Creatine Kinase-MB
CM	Contrast Medium
COPD	Chronic Obstructive Pulmonary Disease
CPAP	Continuous Positive Airway Pressure
CPP	Cerebral Perfusion Pressure
CPR	Cardiopulmonary Resuscitation
CRASH	Clinical Randomization of Antifibrinolytics in Significant Hemorrhage
C-Spine	Cervical Spine
CST	Cosyntropin-Stimulation Test
CT	Computed Tomography
CTA	CT Angiography
DC	Damage Control
DDAVP	Desmopressin
DGAI	German Society of Anesthesiology and Intensive Care Medicine (*Deutsche Gesellschaft für Anästhesiologie und Intensivmedizin*)
DGNC	German Society of Neurosurgery (*Deutsche Gesellschaft für Neurochirurgie*)

DGU	German Trauma Society (*Deutsche Gesellschaft für Unfallchirurgie*)
DIC	Disseminated Intravascular Coagulation
DIVI	German Interdisciplinary Association for Emergency and Acute Care Medicine (*Deutsche Interdisziplinäre Vereinigung für Intensiv- und Notfallmedizin*)
DL	Definitive Laparotomy
DO_2I	Oxygen Delivery Index
DPL	Diagnostic Peritoneal Lavage
DSA	Digital Subtractions Angiography
DSTC	Definitive Surgical Trauma Care
EAES	European Association for Endoscopic Surgery
EAST	Eastern Association for the Surgery of Trauma
ECG	Electrocardiogram
EL	Evidence Level
EMS	Emergency Medical System
EMT	Emergency Medical Technician
ENT	Ear Nose Throat (Otorhinolaryngology)
ERC	European Resuscitation Council
ERG	Electroretinogram
ETC	European Trauma Course
FÄ/FA	Attending Physician (*Fachärztin/Facharzt*)
FAST	Focused Assessment with Sonography for Trauma
FFP	Fresh frozen plasma
FR	French (equivalent to 1 Charrière [CH], thus 1/2 mm)
GCS	Glasgow Coma Scale /Score
GoR	Grade of Recommendation
GOS	Glasgow Outcome Scale
HAES	Hydroxyethyl Starch
Hb	Hemoglobin
HFS	Hannover Fracture Scale
ICP	Intracranial pressure
ICU	Intensive Care Unit
IU	International Unit
IFOM	Institute for Research in Operational Medicine (*Institut für Forschung in der Operativen Medizin*)
INR	International Normalized Ratio
INSECT	Interrupted or continuous slowly absorbable Sutures – Evaluation of abdominal Closure Techniques
ISS	Injury Severity Score
i.v.	intravenous
IVP	Intravenous Pyelography
L1-5	Lumbar Spine Vertebrae
LÄK	Regional Medical Association (*Landesärztekammer*)
LEAP	Lower Extremity Assessment Project
LISS	Less Invasive Stabilization System
LoE	Level of Evidence
LSI	Limb Salvage Index
L-Spine	Lumbar Spine
MAL	Median Axillary Line
MANDAT	Minimum Enrollment Database
MCI	Mass Casualty Incident
MCL	Mid-Clavicular Line
MESS	Mangled Extremity Severity Score
MILS	Manual In-Line Stabilization
MPH	Miles per hour
mRem	Millirem (entspricht 0,01 Millisievert)

MRI	Magnetic Resonance Imaging
MSCT	Multislice Spiral CT
MTRA	Medical-Technical Radiological Assistant
MVA	Motor Vehicle Accident
NaCl	Sodium Chloride
NASCIS	National Acute Spinal Cord Injury Study
NASS CDS	National Automotive Sampling System Crashworthiness Data System
NEF	Emergency Physician Service Vehicle (*Notarzteinsatzfahrzeug*)
NISSSA	Nerve injury, Ischemia, Soft-tissue injury, Skeletal injury, Shock and Age of patient
n. s.	not significant
OMF	Oral and Maxillofacial Surgery
PnS	Paranasal Sinuses
OP	Operation
OPSI	Overwhelming Postsplenectomy Syndrome
OR	Odds Ratio
OSG	Ankle Joint (*Oberes Sprunggelenk*)
PASG	Pneumatic Anti-Shock Garment
pAVD	peripheral Arterial Vascular Disease
PHTLS®	Pre-Hospital Trauma Life Support
PMMA	Polymethylmethacrylate
POVATI	Postsurgical Pain Outcome of Vertical and Transverse abdominal Incision
PPSB	Prothrombin Concentrate
PPV	Positive Predictive Value
pRBC	Packed Red Blood Cells
PSI	Predictive Salvage Index
PTFE	Polytetrafluorethylene
PTS	Polytrauma Score
PTT	Partial Thromboplastin Time
QM	Quality Management
RCT	Randomized Controlled Trial
RISC	Revised Injury Severity Classification
RR	Relative Risk
RSI	Rapid Sequence Induction
ROSC	Return of Spontaneous Circulation
ROTEM	Rotational Thromboelastometry
RöV	X-ray Order (*Röntgenverordnung*)
RTH	Rescue Helicopter (*Rettungshubschrauber*)
RTW	Ambulance/Rescue Vehicle (*Rettungswagen*)
SAGES	Society of American Gastrointestinal and Endoscopic Surgeons
SBP	Systolic Blood Pressure
SCIWORA	Spinal Cord Injury Without Radiographic Abnormality
TBI	Traumatic Brain Injury
SIRS	Systemic Inflammatory Response Syndrome
SR	ED Trauma Bay (*Schockraum*)
STaRT	Simple Triage and Rapid Treatment
STD	Hour (*Stunde*)
TARN	Trauma Audit and Research Network
TASH-Score	Trauma Associated Severe Hemorrhage Score
TEE	Trans-Esophageal Echocardiography
TEG	Thromboelastography
T 1-12	Thoracic Vertebrae
TIK	Trauma Induced Coagulopathy
PC	Platelet Concentrate

tPA	Tissue-specific Plasminogen Activator
Trali	Transfusion Associated Acute Lung Insufficiency
TRGS	Technical Rules for Hazardous Substances (*Technische Regeln für Gefahrenstoffe*)
TRIS	Tris(hydroxymethyl)aminomethane
TRISS	Trauma Injury Severity Score Method
T-spine	Thoracic Spine
TTAC	Trauma Team Activation Criteria
VEP	Visual Evoked Potential
WBCT	Whole Body Computed Tomography
WMD	Weighted mean difference
WS	Spine (*Wirbelsäule*)
XR	Xray

Foreward to the 2016 Update

The first S3 Guideline on the Treatment of Patients with Severe and Multiple Injuries (AWMF Registry Number: 012-019) was initially published in July 2011. With the active participation of eleven medical associations under leadership of the German Trauma Society (Deutschen Gesellschaft für Unfallchirurgie e.V., DGU), 264 recommendations for three main topics based on the phase of care (Pre-Hospital, Emergency Department, Primary Operative Management) were adopted. Because of the regular expiration of the recommendations' validity, preparations for update and potential thematic extension of the guideline were begun at the end of 2013. Auspiciously, the number of medical associations involved in the update process increased to twenty. During the process, 17 chapters have been updated according to current evidence. Two additional chapters have been added. In the chapters that were already present in the first version of the guideline, existing recommendations were adapted, new recommendations were formulated, and out-of-date recommendations were deleted. Authors checked the background text of each chapter for continued relevance, and revised if necessary.

A Background and Goals

Introduction

Medical guidelines are systematically-developed decision-aids for providers and patients regarding the appropriate procedures for special health problems [7]. Guidelines are important tools to make medical care decisions on a rational and transparent basis [6]. The transfer of knowledge they offer should lead to improvements in care [9].
The guideline creation process must be systematic, independent and transparent [6]. The development of level 3 guidelines takes place according to the criteria of the AWMF/ÄZQ (German Medical Center for Quality in Medicine), with all elements for systematic creation [2].

Table 1: Levels of Guideline Development (AWMF) [2]

Level 1	**Expert Group:** A representative group of experts from the respective *Medical Research Society* creates a guideline by informal consensus, which is approved by the board of the society.
Level 2	**Formal Evidence Research or Formal Consensus Development:** Guidelines are developed from conclusions in the scientific literature that have been formally evaluated, or debated and adopted in an established formal consensus process. Formal consensus processes are the nominal group process, the Delphi method, and the consensus conference.
Level 3	**Guideline with all elements of systematic development:** Formal consensus attainment, systematic literature search and evaluation of references, as well as classification of studies and recommendations according to the criteria of evidence-based medicine, clinical algorithms, outcome analysis, decision analysis.

The current guideline is a Level 3 guideline

Background

Accidents are the most common cause of death in adolescents and young adults aged 15-24 years. Almost every third mortality in this group occurred because of an accident [11]. According to statistics of the Federal Institute for Occupational Safety and Health, in 2013 8.58 million people suffered accidental injuries and 21 930 people had fatal accidents [5]. Typically, care of the seriously injured is an interdisciplinary task. Due to the sudden occurrence of the situation, the unpredictability of the number of patients, and the heterogeneity of patient conditions, it is a great challenge for care providers [4].
Initially, for treatment of polytraumatized and seriously injured patients, there was the S1 Guideline of the German Society of Trauma Surgery in 2002. Thus, a comprehensive, interdisciplinary, current, and evidence-based guideline was lacking. This was the rationale behind the creation of the first version of the interdisciplinary guideline for the care of polytraumatized and/or seriously injured patients in 2011.

Requirements for the Guideline

The guideline must meet the following basic requirements:

- Guidelines for the management of polytrauma and patients with severe injuries act as aids to decision-making for specific situations, and are based on the current state of scientific knowledge and on practically-proven procedures.
- Due to the complexity of polytrauma and severe injuries, there is no single ideal concept for management.
- Guidelines need to be constantly reviewed and adapted according to the current state of knowledge.
- The recommendations in this guideline should enable good management for the vast majority of severely injured/polytrauma patients.
- Routine monitoring of treatment and the effects/outcomes of treatment are necessary.
- Regular dialogue of all involved parties (physicians, nursing staff, patients, relatives if possible) should make the goals and methods of polytrauma treatment transparent.

A.1 Guideline Objectives

This interdisciplinary S3 guideline is an evidence-based, consensus-based instrument with the goal of improving management of patients with multiple and severe injuries. Implementation of the recommendations should contribute to structural and procedural optimization in hospitals as well as in prehospital care, and help improve outcomes, measured by mortality rate or quality of life.
The guideline is intended to assist decision-making in specific situations, based on the current state of scientific knowledge and clinically-proven procedures. Thus, the guideline can be used not only in acute treatment situations, but also during follow up and/or for discussions regarding local protocols by quality circles of individual hospitals. Legal (insurance) and accounting aspects are not explicitly covered in this guideline. Regulations of the social security code (SGB VII) apply.
The guideline should be an aid to decision making from an interdisciplinary perspective. Thus, it is suitable to be used to create new treatment protocols for individual hospitals as well as to review existing protocols.
The guideline aims to provide support for the treatment of the vast majority of severe injuries. It is possible that the specific problems of individual patients with defined pre-existing comorbidities or particular injury patterns may not be adequately addressed.

The guideline is intended to stimulate further discussion regarding care optimization for severely injured patients. Thus, constructive criticism and suggestions are expressly welcomed. Ideally, suggested changes should be briefly summarized, referenced, and forwarded to the publisher.
This guideline is also intended to establish interdisciplinary recommendations for the continued process management of severely injured patients during the acute and post-acute phases of care.

A.2 Publisher/Experts/Society Members/Authors

The German Society of Trauma Surgery (Deutschen Gesellschaft für Unfallchirurgie e.V. DGU) is responsible for updates to the S3 Guideline to Treatment of Patients with Multiple and Severe Injuries.
The following professional associations were involved in the creation and update of the guideline:

Initial Version and Update
German Society of General and Visceral Surgery (*Deutsche Gesellschaft für Allgemein- und Viszeral Chirurgie e.V.*)
German Society of Anesthesiology and Intensive Care Medicine (*Deutsche Gesellschaft für Anästhesiologie und Intensivmedizin e. V.*)
German Society of Endovascular and Vascular Surgery (*Deutsche Gesellschaft für Gefäßchirurgie und Gefäßmedizin e.V.*)
German Society of Hand Surgery (*Deutsche Gesellschaft für Handchirurgie e.V.*)
German Society of Oto-Rhino-Laryngology, Head and Neck Surgery (*Deutsche Gesellschaft für HNO-Heilkunde, Kopf- und Hals-Chirurgie e.V.*)
German Society of Oral and Maxillofacial Surgery (*Deutsche Gesellschaft für Mund-, Kiefer- und Gesichtschirurgie e.V.*)
German Society of Neurosurgery (*Deutsche Gesellschaft für Neurochirurgie e.V.*)
German Radiological Society (*Deutsche Röntgengesellschaft e.V.*)
German Society of Thoracic Surgery (*Deutsche Gesellschaft für Thoraxchirurgie e.V.*)
German Trauma Society (*Deutsche Gesellschaft für Unfallchirurgie e.V.*)
German Society of Urology (*Deutsche Gesellschaft für Urologie e.V.*)

Update
German Society of Gynecology and Obstetrics (*Deutsche Gesellschaft für Gynäkologie & Geburtshilfe e.V.*)
German Interdisciplinary Association for Intensive and Emergency Medicine (*Deutsche Interdisziplinäre Vereinigung für Intensiv- und Notfallmedizin e.V.*)
German Society of Pediatric Surgery (*Deutsche Gesellschaft für Kinderchirurgie e.V.*)
German Interdisciplinary Association for Emergency and Acute Care Medicine (*Gesellschaft interdisziplinäre Notfall- und Akutmedizin*)
Society of Pediatric Radiology (*Gesellschaft für Pädiatrische Radiologie e.V.*)
German Society of Plastic, Reconstructive and Aesthetic Surgeons (*Deutsche Gesellschaft der Plastischen, Rekonstruktiven und Ästhetischen Chirurgen e.V.*)
German Professional Association for Emergency Medical Services (Deutscher Berufsverband Rettungsdienst e.V.)
German Society of Transfusion Medicine and Immunohematology (*Deutsche Gesellschaft für Transfusionsmedizin und Immunhämatologie e.V.*)
German Society for Burn Medicine (*Deutsche Gesellschaft für Verbrennungsmedizin e.V.*

Patient Participation
Patient representatives should be included in the update process to give a patient-centered perspective in the S3 Guideline on Treatment of Patients with Severe and Multiple Injuries. Through the Institute for Research in Operative Medicine (IFOM), diverse patient initiatives and self-help groups were queried. Unfortunately, no patient representative was able to participate actively in the guideline update process.

Methodology, Coordination, and Project Management of the 2016 Update

As the leading professional association, the German Trauma Society transferred central coordination of this guideline to the Institute for Research in Operative Medicine.

The tasks of the IFOM were:

- Systematic collection of the areas requiring revision and thematic supplementation for the update based on preliminary research
- Implementation of a prioritization process to define and prioritize the different subject areas
- Coordination of the project group
- Methods support and quality assurance
- Systematic literature review
- Literature search
- Extraction and systematic evaluation of the quality of the included studies as well as the allocation of evidence levels (LoE)
- Preparation of evidence reports
- Data management
- Structural and editorial standardization of the guideline text

- Coordination of the necessary discussions, meetings and consensus conferences

Overriding Thematic Responsibilities for the 2016 Update

The initial version of the guideline was divided into three main sections according to the phase of care: Pre-Hospital Care, Emergency Department, and Primary Operative Management, and this structure was maintained for the update.

Coordinators were assigned responsibility for each of these treatment phases:

Pre-Hospital Care
Prof. Dr. med. Christian Waydhas
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Emergency Department
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58448 Witten

Prof. Dr. med. Frank Hildebrand
RWTH Aachen University Hospital
Department of Trauma and Reconstructive Surgery
Pauwelsstraße 30
52074 Aachen

Tasks of the 2016 Update coordinators were:

- Assignment of authors to topics needing update
- Specialty expertise in the prioritization of the topics
- Support to the authors for preparation of the approved recommendations (including grade of recommendation) and for the updates of the background text
- If necessary, update of the introductory background text for the respective chapter sections
- Final review and control of the chapters created within a thematic section

Moderation, Coordination and Project Management of the Initial 2011 Version

As the leading professional association, the German Trauma Society transferred central coordination of this guideline to the Institute for Research in Operative Medicine (*Institut für Forschung in der Operativen Medizin*, IFOM).

The tasks were:

- Coordination of the project group
- Methods support and quality assurance
- Systematic literature review
- Literature search
- Data management
- Structural and editorial standardization of the guideline text
- Coordination of the necessary discussions, meetings and consensus conferences
- Management of financial resources

Overall Thematic Responsibilities for the Initial 2011 Version

The guideline was divided into three main sections: Prehospital (now Pre-Hospital Care), Emergency Department, and Emergency Surgery (now Primary Operative Management). Coordinators were assigned responsibility for each of these treatment phases.

The tasks were:

- Establishing guideline contents
- Screening and evaluation of the literature for the different treatment strategies for polytrauma and severely injured patients, development and coordination of the guideline text

The AWMF, represented by Professor I. Kopp, provided methods guidance in developing the guideline.

A.3 Target User Groups

The primary target users of the guideline are the physicians and other medical professionals treating patients with multiple and severe injuries. The recommendations are for adult patients. Recommendations for the care of pediatric and adolescent patients are only occasionally specified in the guideline.

B Methods

B.1 Methods 2016 Update

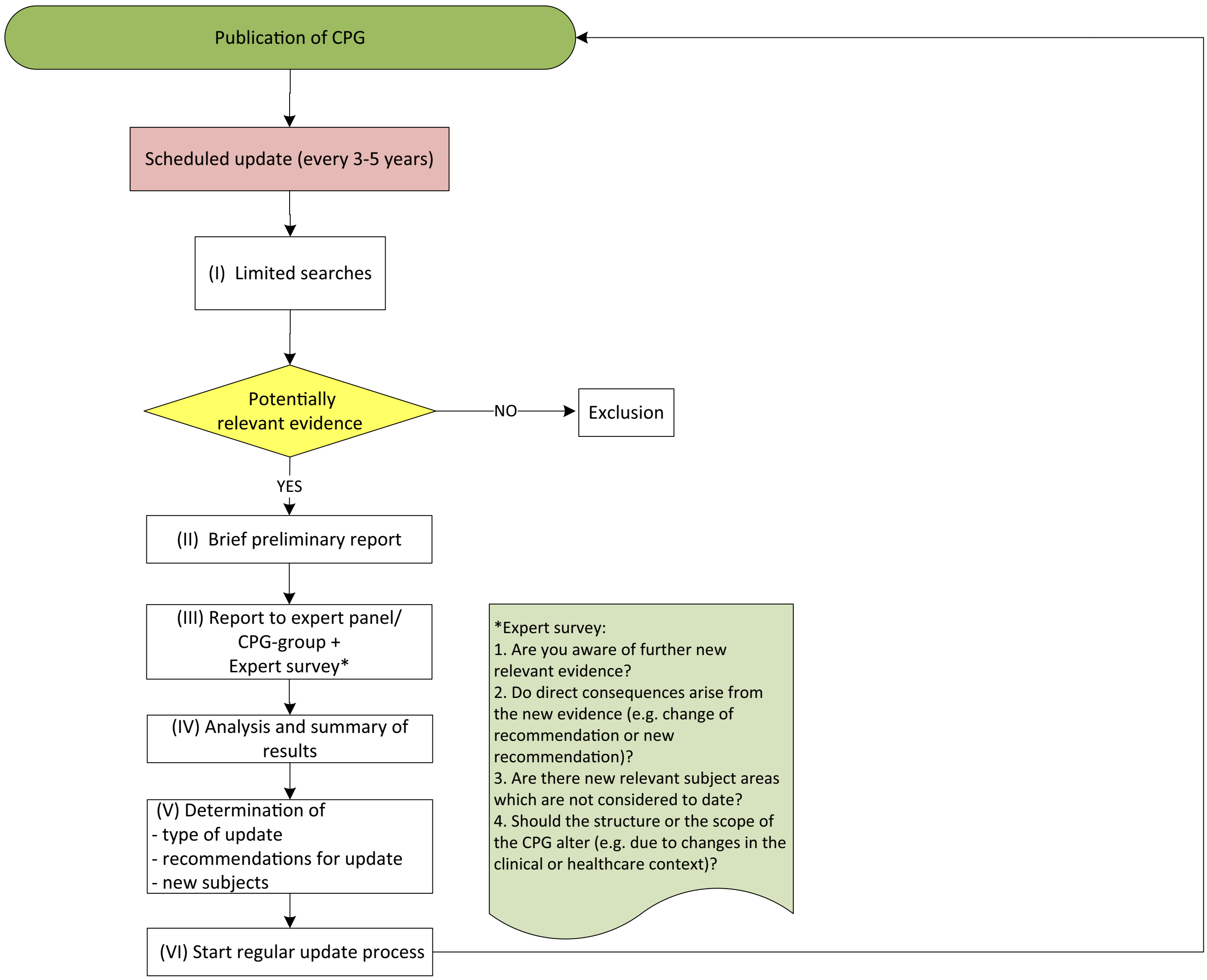
1. Determination of the Requirements for Update and Supplementation

Prior to the actual update, the time from January until June 2014 was used to prioritize updated and newly introduced topics and recommendations.
As a first step, preliminary screening was carried out. As much as possible, these were based on the original searches of the initial guideline, but were less comprehensive than the final searches, and were limited in part to the relevant core journals and particular study types. The preliminary literature searches were performed within the MEDLINE database (via PubMed) for the time period of 2009 till January 14, 2014, using free text and subject headings (Medical Subject Headings/MeSH).
The results of the preliminary searches were screened by two independent reviewers according to predefined exclusion criteria (see Table 2). The abstracts of studies identified as potentially relevant were then assigned to the existing chapters of the guideline in a preliminary overview.
In the next step, the overview of potentially relevant studies was sent to the guideline group together with an online survey. One goal of the survey was to identify relevant literature in addition to results of the preliminary screening as well as any newly relevant topics. Another goal was to ask whether the new evidence warranted update (e.g. revisions or deletion of existing recommendations).
Based on the results of the preliminary screening and expert surveys, decisions regarding priority for updates/revision of thematic areas/chapters were made at a constituent consensus conference held in Cologne on June 4, 2014.
Figure 1 gives an overview of the entire decision-making process.
In addition, the steering committee later identified other individual topics with high update requirements.
Another short survey was sent to all delegates in June 2015 regarding the need for updates in individual chapters that had not yet been revised.
Some chapters identified as needing updates could not be revised due to lack of time and budget. These have been appropriately marked in the guideline and will be accounted for in the next regularly scheduled update.

Table 2: Inclusion Criteria for the Preliminary Screening

1. **Study population**: Adult patients ($\geq$ 14 years) with polytrauma or trauma-related severe injury
2. **Study type**: systematic review (based on comparative studies), RCT, non RCT/CCT, prospective cohort studies, comparative registry database studies.
3. **Language of publication**: English or German
4. No multiple publications without additional information
5. Full text can be obtained
6. Not considered in the previous guideline

Figure 1: Decision-Making Algorithm on Need for Update/Supplementation (according to Becker et al. 2014 [3])



2. Search for existing guidelines updates

A systematic search for national and international guidelines was carried out within the databases of the AWMF, The Guideline International Network (GIN), and the National Guideline Clearinghouse (NGC) as well as the Internet sites of interdisciplinary and specialty-specific guideline providers. The guideline databases were searched using keywords and/or free text searches. The respective search strategies were based on the structure and capabilities of the websites.

Table 3: Inclusion and Exclusion Criteria for Guideline Searches

E1	It is a guideline
E2	The guideline contains recommendations on the subject of trauma
E3	The guideline contains recommendations for the treatment of polytrauma and/or severely injured patients
E4	The guideline contains recommendations for one or more of the following topics:
	Diagnostics
	Patient information/communication
	Therapy (psychotherapy, pharmacotherapy/other non-drug therapies)
	Coordination of measures and cooperation of providers
E5	Contains recommendations on Pre-Hospital, Emergency Department and/or Primary Surgical care in Germany or the guidelines are classified as transferable to the target situation.
E6	Publication period: 2012
E7	Language of publication: English or German
E8	The guideline is available at no cost in full text format
E9	The authors refer to the guideline as current or the revision date has not been exceeded and there is no updated version currently available.
E10	The guideline was classified as methodologically appropriate (methodological quality corresponds to S3) by two independent evaluators using the AGREE-II instrument
E11	Search strategy (of the relevant chapter) and evidence tables must be specified

Search Terms Used

Trauma, traumatic injur*, polytrauma, injur*

In some cases, additional keywords were also searched that were relevant to the individual chapter to be updated.

Research Period

Date of the initial search:	6 August 2013
Date of the last search:	23 August 2013
Post-Search:	23/24 July 2014

A detailed search protocol with statements of inclusion or exclusion criteria for individual guidelines can be seen at IFOM.

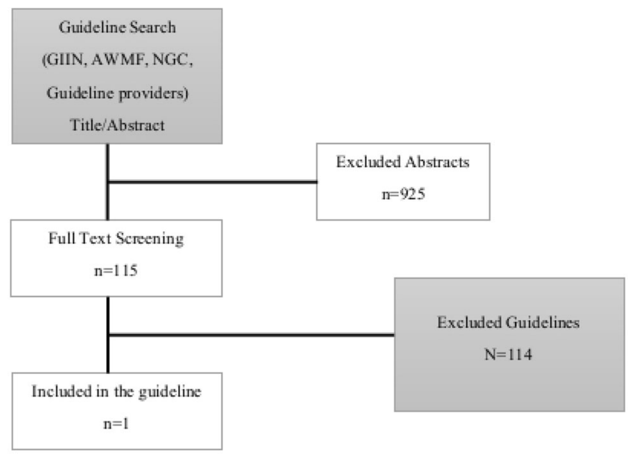
Assessment of methodological quality of the guidelines

The guidelines, which were considered according to theme for the adoption or adaptation of a recommendation, were assessed using the AGREE-II instrument by two independent evaluators. When there was disagreement, a third evaluator was called in. The assessments of the individual guidelines can be seen at IFOM.

Results

In total, 1040 guidelines were identified and 115 assessed in full text. Because of the specific topic of polytrauma/severe injury management in the initial treatment phases, many guidelines could not be included. In addition, many of the guidelines could not fulfill the E10 criterion and were excluded because of methodological aspects.

Figure 2: Flowchart Guideline Research



A guideline was included for the "Coagulation" chapter. The relevant newly adopted and/or adapted recommendations from the source guideline are identified in the corresponding chapter.

3. Systematic Literature Search Updates

For the update, one literature search per chapter was performed in the MEDLINE (via PubMed) and EMBASE databases. The search was performed using both medical keywords (Medical Subject Headings/MeSH) and free text searches. Search strategies to account for all relevant search terms for each chapter were agreed upon by the authors and chapter authorities in advance. Searches were carried out from the publication date of the initial version of each respective chapter. A detailed account of the search time period per chapter is given in the guideline. For newly submitted chapters determined during the upgrade process, searches were performed beginning in 1995. English and German were set as the languages of publication.

The systematic literature review was conducted by the Institute for Research in Operational Medicine (*Institut für Forschung in der Operativen Medizin*).

Selection of the Relevant Literature Update

For each chapter, inclusion criteria were defined a priori, as shown in the guideline report. Only literature with high evidence levels was included. Thus, the conclusions made according to this literature are based on study designs containing the least risk for distortion or bias. First, the titles and abstracts of the identified literature were screened against the inclusion criteria by two independent reviewers. In cases of potential relevance, reviews of the full text followed. Disagreements were discussed until consensus was reached. A detailed account of the screening process is presented in the guideline report.

Evaluation of Relevant Literature Update

Methodological quality of the primary studies was performed using checklists from the National Institute for Health and Clinical Excellence (NICE). The AMSTAR instrument was used to assess methodological quality of systematic reviews. Evaluations were performed independently by two experts. Any discrepancies were discussed until consensus was reached (see guideline report).

Classification of Study Type and Level of Evidence Assignment Update

The classification of the study type was performed according to the Hartling et al. algorithm. The level of evidence (LoE) was allocated according to the March 2009 provisions of the Oxford Centre for Evidence-Based Medicine. LoE is based on the study type. In addition, the risk of bias as well as the consistency and precision of the effect estimator was taken into account. When necessary, the LoE was downgraded and marked with an arrow (↓).

Extraction of Primary Studies Update

Extraction of studies was performed with pre-tested, standardized extraction tables. Data extraction was performed by one expert reviewer and controlled for quality by a second. Any discrepancies were discussed until consensus was reached.

For primary studies, the following data were extracted, depending on the type of study:

- Title, date of publication, and aim of the study
- Baseline Characteristics
- Age, gender, ISS, TRISS, RTS, GCS or, if not given, the items used to assign scores; if necessary, further scores quantifying the severity of injury and/or relevant influencing variables[1]
- Inclusion/Exclusion criteria
- All demographic and clinical inclusion and exclusion criteria were extracted. Formal inclusion criteria were not considered (e.g. declaration of consent).
- Other characteristics:
- Region: country in which the study was performed, contextual information, i.e. data source, year
- Patient Flow:
- The number of included and evaluated patients well as patients who discontinued study participation (dropouts, lost to follow up). If this number was not given per group, and instead only as group-related information on patient flow regarding analysis, then the difference between randomized/included and evaluated patients was given.
- Description of the intervention/control group:
- The most detailed possible reports were made of the intervention and control or in diagnostic studies of the index and reference tests.
- Results to the endpoints of studies:
- The rate of each event at the endpoint (%), or for rare events the number per group, as well as the relative effect measures (odds ratio, relative risk, hazard ratio), if available, were extracted. Statistical significance was indicated with p-values and/or confidence intervals (CI). For continuous variables, the mean value or the mean value difference was indicated with CI or p-values. If no two-sided test was applied, it is indicated in brackets behind the p-value. When there were multiple endpoints, the final follow-up was used, provided that it represented a cumulative view of all events. If treatment and follow-up phases were observed separately, the events were indicated for each individual timeframe.

Extraction for Systematic Review Studies Update

For systematic review studies, data extraction included entries for study selection inclusion/exclusion criteria, research timeframe, as well as input on interventions and controls. In addition, for each comparison, the heterogeneity (I^2) as well as the numbers of included studies (N) and included patients (n) were indicated. For the pooled results of meta-analyses, the relative or standardized effect measures were extracted. In cases where no meta-analysis was performed, the results were reported descriptively.

4. Formulation of Recommendations and Consensus Statements Update

The professional associations involved in the project each designated at least one delegate as a specialty representative to contribute to creation of the guideline. Each society had a voice in the consensus process. Votes were taken anonymously using a TED system (Turning Point Version 2008). Distribution of the TED devices was carried out with full transparency at the beginning of each consensus conference, and receipt of the voting device was confirmed by signature of each delegate.

The recommendations as well as the grade of recommendation were adopted during four consensus conferences (March 20-21, 2015, May 13, 2015, September 29, 2015, and November 17, 2015). The first, second and fourth consensus conferences were moderated by Prof. Dr. Edmund Neugebauer and the third guidelines conference by Prof. Dr. Bertil Bouillon. Prof Dr. Bouillon had no vote and maintained impartiality during discussions and

[1] Trauma.org: http://www.trauma.org/archive/scores/triss.html

balloting. The logs of each conference can be viewed at the Institute for Research in Operative Medicine (IFOM). PD Dr. med Ulrich Linsenmaier was present as external consultant at two consensus conferences.

Within the guideline update process, the following options to vote on recommendations were possible:

1. The recommendation of the initial version remains valid, requires no changes, and can therefore remain,
2. Individual elements of the recommendation require modification,
3. The recommendation is no longer valid and will be deleted,
4. New recommendations will be developed.

The voting process during the conferences consisted of six steps:

1. Presentation of the suggested recommendations made by a member of the author group,
2. Chance for questions, additions, and/or objections from the plenary,
3. Recording by the moderator of the opinions and alternatives proposed by the participants regarding the recommendations themselves as well as on the degree of recommendation,
4. Vote on the recommendations and grade of recommendations,
5. Potential discussion of points for which no "strong consensus" was achieved in the first round of voting,
6. Final vote with the TED system.

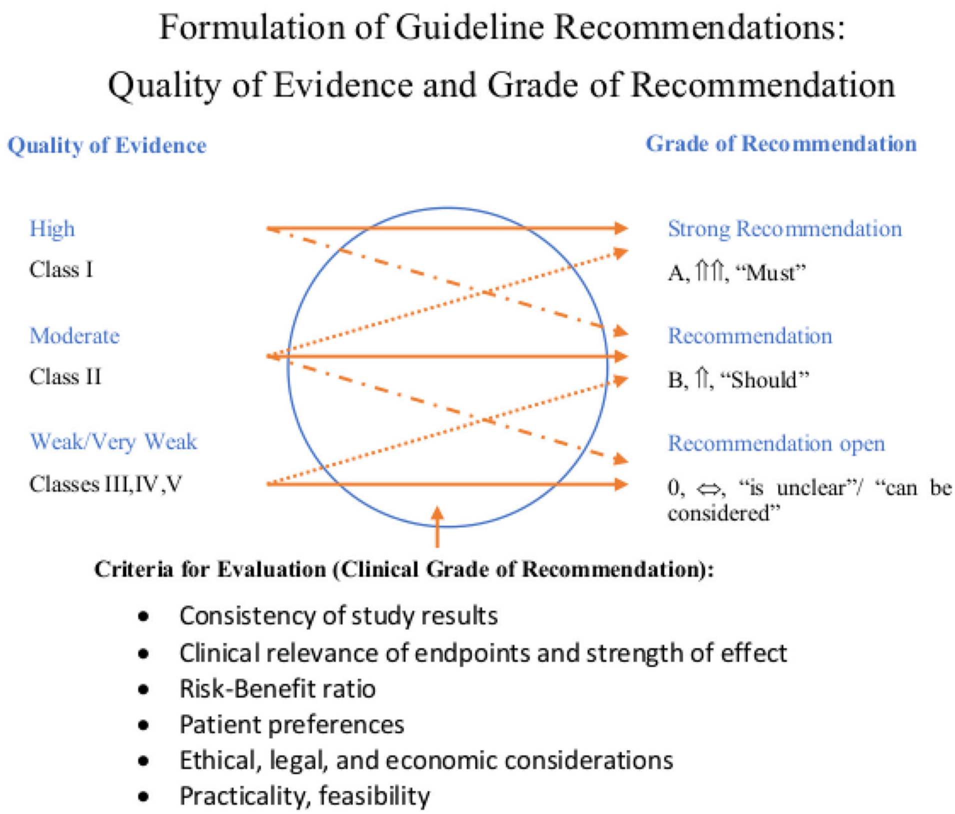
Most of the recommendations were adopted within the "strong consensus" range (approval by >95 of participants). Areas in which strong consensus was not achieved are identified in the guideline, and the various positions are presented. The strength of consensus was classified according to the rules and regulations of the AWMF as follows [1]:

Table 4: Classification of Consensus Strength

Strong Consensus	> 95 % of participants in agreement
Consensus	> 75–95 % of participants in agreement
Majority Approval	> 50–75 % of participants in agreement
No Consensus	< 50 % of participants in agreement

Three grades of recommendation (GoR) A, B, and 0 were assessed. Formulation of the key recommendations was thus, "must", "should," or "may/can." In addition to the underlying evidence, benefit risk considerations, directness and homogeneity of the scientific evidence, as well as clinical expertise were used for determination of the GoR.[1].

Figure 3: From Evidence to Recommendation [1]



Good (Clinical) Practice Points (GPP)

If no (direct) evidence for a recommendation or goal was available, an expert opinion could be formulated using the wording of the evidence-based recommendations (must/should/may), but instead of a GoR, it would receive graduation/recommendation GPP points (good clinical practice points). This "clinical consensus point" was essentially based on the clinical experience of the guideline group, and thus represents the current clinical standards in treatment when evidence is not available.

5. Updated Topics

Within the recommendation headings it was noted when each topic was created or updated, and whether it was modified or newly introduced. The following categories are used for identification:

- 2011 = The recommendation is part of the original guideline from 2011, and is still current and not voted on.
- 2016 = the recommendation is from the year 2011 and is part of the 2016 update. It was approved without changes.
- modified 2016 = The recommendation is from the 2016 update. The recommendation has been revised.
- new 2016 = The recommendation is part of the 2016 update. The recommendation has been newly created.

Overview of Updated Chapters

No.	Chapter	Update Status
Pre-Hospital Care		
1.1	Introduction	Updated 2016
1.2	Airway Management, Ventilation, and Emergency Anesthesia	Updated 2016
1.3	Volume Replacement	Updated 2016
1.4	Thorax	Updated 2016
1.5	Traumatic Brain Injury	Updated 2016
1.6	Spine	Updated 2016
1.7	Extremities	Updated 2016
1.8	Urogenital tract	Background text updated 2016
1.9	Transport and Target Hospital	Updated 2016
1.10	Mass Casualty Incident (MCI)	Background text updated 2016 Need for update has been registered
Emergency Department		
2.1	Introduction	Updated 2016
2.2	Emergency Department - Staffing and Equipment	Background text updated 2016

No.	Chapter	Update Status
		Need for update has been registered
2.3	Emergency Department Trauma Team Activation	Background text updated 2016
2.4	Thorax	Updated 2016
2.5	Abdomen	Background text updated 2016
2.6	Traumatic Brain Injury	Background text updated 2016
2.7	Pelvis	Updated 2016
2.8	Urogenital tract	Background text updated 2016
2.9	Spine	Background text updated 2016
2.10	Extremities	Background text updated 2016
2.11	Hand	Original version remains valid.
2.12	Foot	Background text updated 2016
2.13	Mandible and Midface	Original version remains valid.
2.14	Neck	Original version remains valid.
2.15	Resuscitation	Updated 2016
2.16	Coagulation System	Updated 2016
2.17	Interventional Hemorrhage Control	Updated 2016
2.18	Imaging	newly created 2016
Primary Operative Management		
3.1	Introduction	Updated 2016
3.2	Thorax	Updated 2016
3.3	Diaphragm	Background text updated 2016
3.4	Abdomen	Updated 2016
3.5	Traumatic Brain Injury	Updated 2016
3.6	Urogenital tract	Background text updated 2016
3.7	Spine	Background text updated 2016
3.8	Upper Extremity	Background text updated 2016
3.9	Hand	Background text updated 2016
		Need for update has been registered
3.10	Lower Extremity	Background text updated 2016
3.11	Foot	Background text updated 2016
3.12	Mandible and Midface	Original version remains valid.
3.13	Neck	Original version remains valid.
3.14	Thermal Skin Injuries and Burns	newly created 2016

For the next revision, the following new chapters are planned:

- Analgesia
- Damage Control Vessels
- Training (Hard and soft skills)

Funding of the Guideline and Disclosure of Potential Conflicts of Interest Update 2016

Financial resources for the methods support and covering costs for literature acquisition, organization of the consensus conferences, and of materials were provided by the German Trauma Society. Travel costs incurred by participants of the consensus conferences were covered by the medical societies/organizations sending representatives or by the participants themselves. The authors, delegates, and members of the steering committee creating the guideline volunteered their time and effort free of charge.

To make the update process as transparent as possible, all participants were requested to submit an explanation of any potential conflicts of interest prior to beginning work on the guideline. All participants of the consensus conference disclosed potential conflicts of interest in writing. Once submitted, these were always available to be updated and could be accessed by all members of the guideline group. Prior to each consensus conference, a current summary of the delegates' conflicts of interest declarations was sent along with a request for evaluation. Prior to the beginning of each conference, it was asked whether any of the delegates present saw grounds for any person listed in the summary of declarations to be excluded from the vote. Planned regulation of conflicts of interest through exclusion of any individual participant from discussions or votes was discussed by the delegates in each session. No delegates needed to be excluded from the voting. The risk of guideline content distortion due to conflict of interest was also countered by the balanced composition of the guideline group, the preparation of evidence by an independent institute (IFOM), and the use of a formal consensus process with independent moderation. An overview of the declarations of potential conflicts of interest by all coordinators, methodologists, medical society delegates, authors, and organizers can be found in the Appendix of this guideline. In addition, the forms used to disclose potential conflicts of interest can be requested from the Institute for Research in Operative Medicine (IFOM).

B.2 Methods of the Original 2011 Version

The guideline project was initially announced in December 2004 and again in May 2009.

The "Guideline on Treatment of Patients with Severe and Multiple Injuries" was created according to a structured, planned, reliable process. It is the result of a systematic literature search and critical assessment of available data using scientific methods as well as discussion with experts in a formal consensus process.

Literature Search and Selection of Evidence Initial Version

The key questions for the systematic literature search and evaluation were formulated based on preliminary work from 2005. The literature searches were carried out in the MEDLINE database (via PubMed) using medical keywords (Medical Subject Headings/MeSH), partly supplemented by a free text search. The filter recommended in PubMed was used to identify systematic reviews. Supplementary searches were conducted in the Cochrane Library (CENTRAL) (in this case with keywords and text words in the title and abstract). The publication period selected was 1995-2010, and German and English as the publication languages.
The literature searches were carried out partly by the Institute for Research in Operative Medicine (IFOM) and partly by the authors themselves. The results of the literature searches, sorted according to topic, were forwarded to the individual authors responsible for each topic.
The underlying key questions, the literature searches carried out with date and number of hits and, if applicable, search limitations were documented.

Selection and Evaluation of the Relevant Literature Initial Version

The authors of each chapter selected and evaluated the literature included in the guideline (see Guideline report). This was carried out according to the criteria of evidence-based medicine. Sufficient randomization, allocation concealment, blinding and statistical analysis were taken into account.
The evidence statement for the recommendations was based on the evidence classification of the Oxford Center of Evidence-Based Medicine (CEBM), March 2009 version. In formulating the recommendations, priority was given to studies with the highest level of evidence available (LoE).

Table 5: CEBM Evidence Classification [10]

Grade	Studies of Therapy/Prevention/Etiology
1a	Systematic Overview of Randomized Controlled Studies (RCT)
1b	RCT (with narrow confidence interval)
1c	All-or-none principle
2a	Systematic Overview of Well-Planned Cohort Studies
2b	A well-planned cohort study or a RCT of less quality
2c	Outcome studies, ecological studies
3a	Systematic Overview of Case-Control Studies
3b	Case-control study
4	Case Series or Cohort/Case-Control Studies of Lesser Quality
5	Expert opinions without explicit evaluation of the evidence or based on physiological models/laboratory research.

Three grades of recommendation (GoR) A, B, and 0 were assessed. Formulation of the key recommendations was thus, "must", "should," or "may/can." In addition to the underlying evidence, benefit risk considerations, directness and homogeneity of the scientific evidence, as well as clinical expertise were used for determination of the GoR [6].

Formulation of Recommendations and Consensus-Finding Initial Version

The professional associations involved in the project each designated at least one delegate as a specialty representative to contribute to creation of the guideline. Each society had a voice in the consensus process.
The recommendations as well as the grade of recommendation were adopted during four consensus conferences (March 18-19, 2009, May 30, 2009, September 8, 2009, and November 26-27, 2009).
The voting process during the conferences, performed with help of the TED system, consisted of six steps:

- the opportunity to review the guideline manuscript before the conference and to compile notes on the proposed recommendations and grades;
- presentation and explanation from each responsible author on the pre-formulated proposals for recommendations;
- recording by the moderator of the opinions and alternatives proposed by the participants regarding the recommendations, with moderator contributions solely for clarification;
- voting on all recommendations and grades of recommendations, as well as the suggested alternatives;
- discussion of points for which no "strong consensus" was achieved in the first round of voting;
- final vote.

Most of the recommendations were adopted within the "strong consensus" range (approval by >95 of participants). Areas in which strong consensus was not achieved are identified in the guideline, and the various positions are presented. In assessing consensus strength, the following consensus classification was created in advance:

- Strong Consensus > 95 % of the participants in agreement
- Consensus > 75-95 % of participants in agreement
- Majority Approval > 50-75 % of participants in agreement
- No Consensus < 50 % of participants in agreement

The logs of each conference can be viewed at the Institute for Research in Operative Medicine (IFOM). The Delphi method was then applied to recommendations for which no consensus could be reached in the consensus conferences. A detailed methods report is available for viewing on the AWMF website and has been filed at the Institute for Research in Operative Medicine (IFOM).

Funding of the Guideline and Disclosure of Potential Conflicts of Interest Initial Version

Financial resources for the methods support and covering costs for literature acquisition, organization of the consensus conferences, and of materials were provided by the German Trauma Society and the Institute for Research in Operative Medicine of the University of Witten/Herdecke. Travel costs incurred by participants of the consensus conferences were covered by the medical societies/organizations sending representatives or by the participants themselves.

All participants of the consensus conference disclosed potential conflicts of interest in writing. A summary of the declarations of potential conflicts of interest by all coordinators, methodologists, medical society delegates, authors, and organizers can be found in the Appendix of this guideline. In addition, the forms used to disclose potential conflicts of interest can be requested from the Institute for Research in Operative Medicine (IFOM).

Warmest thanks are extended to the coordinators of the individual subsections, the authors, and participants in the consensus process for their completely voluntary work.

B.3 Distribution and Implementation

- Distribution of the guideline will be carried out as follows:
- via the internet: AWMF website (http://www.awmf-online.de) as well as the websites of the medical societies and professional organizations involved in the guideline
- via printed media:

  Publication of the guideline as a manual/book by the DGU. Copies will be made available to all hospitals involved in the DGU Trauma Network. In addition, all hospitals involved will be notified in writing regarding where and how the guideline can be viewed on the AWMF homepage.

  Publication of excerpts of the guideline and implementation strategies in the journals of the participating medical societies. To simplify use of the guideline, a summary version of the guideline containing the key recommendations will be published in "Notfall- und Rettungsmedizin" [German medical journal].

- via conferences, workshops, professional training courses offered by the participating medical societies.

Various complementary measures are to be implemented in this guideline. In addition to the presentation of the recommendations at conferences, a link to topic-specific professional training courses is planned.

In addition, implementation at all the German DGU trauma network hospitals will be evaluated approximately one year after guideline publication. In particular, information should be collected regarding guideline use and practical suggestions for other users.

Quality Indicators and Evaluation

Audit filters were developed for the DGU Trauma Registry as criteria for quality management. Based on available audit filters, the following criteria were established for this guideline:

Process quality for evaluation in the pre-hospital care phase:

- duration of prehospital time from accident to hospital admission for severely injured patients with ISS $\geq$ 16 [min $\pm$ SD]
- intubation rate in patients with severe chest injury (AIS 4-5) by the emergency physician [%, n/total]
- intubation rate in patients with suspected traumatic brain injury (unconscious, Glasgow Coma Scale [GCS] $\leq$ 8) [%, n/total]

Process quality for evaluation of the emergency department phase:

- time from hospital admission to performance of chest X-ray in severely injured patients (ISS $\geq$ 16) [min $\pm$ SD]
- time from hospital admission to abdominal/chest ultrasound in cases of severe trauma (ISS $\geq$ 16) [min $\pm$ SD]
- time to computed tomography (CT) scan of the cranium (CCT) in pre-hospital unconscious patients (GCS $\leq$ 8) [min $\pm$ SD]
- time to full-body CT scan on all patients, if carried out [min $\pm$ SD]
- time from emergency arrival to completion of diagnostic survey in severely injured persons, if this has been completed normally (ISS $\geq$ 16) [min $\pm$ SD]
- time from emergency arrival to completion of diagnostic survey in severely injured persons, if interrupted due to emergency (ISS $\geq$ 16) [min $\pm$ SD]

Outcome Quality for Overall Evaluation:

- standardized mortality rate: observed mortality divided by the expected prognosis based on RISC (Revised Injury Severity Classification) in severely injured patients (ISS $\geq$ 16)
- standardized mortality rate: observed mortality divided by the expected prognosis based on TRISS (Trauma

Injury Severity Score Method) in severely injured persons (ISS $\geq$ 16)

The routine collection and evaluation of these data offer a vital opportunity to monitor improvements in the quality of management of patients with multiple and severe injuries. From this it is not possible to ascertain which effects are due to the guideline. Quality indicators should continue to be developed based on the aforementioned criteria.

B.4 Guideline Validity and Updates

The present guideline is valid until June 2021. The German Trauma Society is responsible for initiating the update procedure. The next update is planned to address the topics of analgesia, damage control vessels, and a special chapter on training (hard and soft skills).

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1. Pre-Hospital Care

1.1 Introduction

Professional treatment of seriously injured patients begins at the accident scene with a structured rescue service. Already at this first phase of treatment, the introduction of life-saving measures, a time-critical approach, and transport to the appropriate target hospital set the overall trajectory of the course to come.

Often before the emergency physician arrives, an emergency rescue service without a physician is first at the scene of the accident [1]. Thus, the "Pre-Hospital Care" section of this guideline is directed not only towards physicians, but also to emergency medics, paramedics, and other pre-hospital assisting personnel.

Five years ago, the first comprehensive AWMF guideline for the treatment of severely injured patients was published, and is updated now for the first time. What has changed since then - and what has not?

For the pre-hospital care section - but not only here - a number of situations have been singled out and worked out in more detail, situations in which pre-hospital measures could be life-saving and in which full implementation of these measures could prevent potentially avoidable deaths, for example situations with problems securing the airway, decompression of a tension pneumothorax, or insufficient hemorrhage control [3].

In the chapter, "Airway Management, Ventilation, and Emergency Anesthesia," new recommendations regarding the use of video laryngoscopy have been included. An increasing collection of evidence shows clearly that use of video laryngoscopy enables higher success rates of endotracheal intubation for very experienced as well as less-experienced users. However, since advantages in survival with the use of video laryngoscopy have not yet been proven, the recommendations have been formulated as "good clinical practice points" (GPP).

For the treatment of thoracic trauma, the importance of rapid decompression for tension pneumothorax has been more strongly emphasized. Several analyses have identified tension pneumothorax as one of the most important preventable causes of death.

The importance of hemostasis outside of the operating room has moved further into the foreground. A substantial new section has been added to the "Extremities" chapter dealing with profusely bleeding wounds and the use of newer methods for hemorrhage control such as tourniquets and hemostatic bandages. In particular, situations are defined in which tourniquets can be considered a primary management option. In this context, the reader should also pay attention to the "Pelvis" chapter in the "Emergency Department" section of the guideline, in which aspects of examination and emergency stabilization are considered that are also relevant to the pre-hospital care situation.

Since publication of the last S3 guideline, numerous studies have addressed the use and performance of cardiopulmonary resuscitation for cases of trauma-induced cardiac arrest [11, 14, 18, 20]. Registry data show that in traumatic cardiac arrest, even after blunt trauma, resuscitation measures can have positive results with good neurological outcomes [9]. For this reason, the extensive and reorganized "Resuscitation" chapter in the "Emergency Department" section must be pointed out, as it is also extremely relevant for pre-hospital management. Here, the special measures for resuscitation after trauma have been clearly prioritized and presented, and in particular, the differences versus resuscitation for classic cardiac or pulmonary induced arrest are highlighted. The algorithms and recommendations presented are closely aligned with the international guidelines of the ERC (European Resuscitation Council).

The chapter "Thermal Skin Injuries and Burns" is completely new and is dedicated mostly to the special management of severely injured patients with concomitant burn injuries. It is therefore considered a supplement to existing guidelines [7, 17]. That chapter is found in the "Primary Operative Management" section of this guideline, but also contains information relevant to pre-hospital care.

Another chapter that has undergone revision is the "Mass Casualty Incident" chapter. A mass number of trauma patients represents a rare, but very challenging situation. Current events and the global political situation clearly show that being prepared for a mass attack, e.g. a terrorist strike, is more necessary than ever. In a modern and mobile society, however, there are also other scenarios with large numbers of severely injured persons, e.g. the recent train accident at Bad Aibling, which are unavoidable despite high safety standards. Prior to arrival of the executive emergency physician on duty, the primary tasks focusing on triage and allocation of scarce resources and treatment capacity must be handled by the first emergency physician on the scene.

It cannot be stressed often enough that treatment of severely injured patients is a time-critical enterprise. Interestingly, the pre-hospital time, i.e. the time from the accident until arrival in the Emergency Department, is apparently not an independent risk factor, at least not for all patients as a whole. Nevertheless, even data collection by the best current risk prediction tool, the RISC II [13], identifies pre-hospital time as an independent risk factor predicting mortality. On the other hand, it is known that in cases of severe intra-abdominal bleeding, a time delay of one minute increases mortality by 3% [5]. Since the predictive power of recognizing these injuries in the pre-hospital setting is low and the concerned patients can easily go unrecognized [2, 10, 16], it is advisable to transport all patients with potentially severe injuries as quickly as possible to the hospital, where the full range of diagnostic and targeted interventions can be performed. In the end, however, whether some time-consuming procedures are performed at the accident scene or are postponed until the early hospital phase must be weighed. It certainly plays a role here as to how urgent the indication for an intervention is, whether there are particular difficulties in carrying it out, or whether individual skills are sufficient to do it safely and correctly. In the meantime, it has also been found that the time gained by skipping interventions in the pre-hospital phase is lost again during the Emergency Department phase. Thus, the balance between the "load and go" and "stay and play" approaches to pre-hospital management must be based first and foremost on the urgency of the required intervention [12]. Life-saving interventions should not be foregone in favor of a shorter pre-hospital time. Conversely, some measures, e.g. surgical hemostasis of internal bleeding, must be performed in the hospital. As a guideline, the Key Points Paper on Emergency Medical Management of Patients recommends a maximum pre-hospital time of 60 minutes [8]. This does not preclude the fact that faster transport for certain patient groups would be better.

Regarding the critical time period as well as rapid injury-appropriate management, selection of the appropriate hospital is of great importance. Germany now has a national system of certified trauma centers in three levels of care, resulting from a transparent catalog of available services. This catalog is revised and published every four years in the white paper Treatment of the Severely Injured [6]. Recently, the benefits of air rescue in particular have proliferated, because it seems to be associated with improved survival after severe accident-related trauma. One suspected reason for this advantage is the ability of helicopters to reach an appropriate target hospital more rapidly than ground-based rescue services, especially when the hospital is far away. Particularly when it comes to special requirements, e.g. a neurosurgical department in cases of severe TBI, center-related effects could be a reason for the benefits of air rescue. This topic is a focus of the chapter "Transport and Target Hospital," which has been correspondingly expanded and made more detailed. Here again, the Key Paper [8] calls for accessibility-oriented treatment with a recourse to national treatment capacity involving air rescue regardless of the time of day.

During registration in the target hospital, it's important that the treatment of the patient continues smoothly and without unnecessary loss of time. As a benchmark, the Key Paper calls for a time interval of 90 minutes from accident until the start of lifesaving, operative interventions [8]. The hub of continued hospital treatment is in the trauma bay of the Emergency Department. Criteria for the requirements there are listed in the "Trauma Team Activation" chapter of the "Emergency Department" section of this guideline. The guideline group placed low priority on the revision of this chapter. However, questions surrounding over- and under-triage based on the recommendations there continue to present in daily practice as a stress test for hospital resources. In 2012, the US Center for Disease Control (CDC) published an update of its recommendations regarding assignment of patients to a trauma center, which has also been translated into German [19]. The criteria given there are similar to the German trauma team activation criteria. The main problem, however, is that especially the criteria regarding accident mechanism, in the absence of other criteria, might invite speculation that trauma team management is not indicated. Leaders in the emergency medical services (EMS) and the medical director of the EMS should work together with the trauma network to develop locally-adapted processes to meet their respective needs. In view of the difficulties in making an accurate diagnosis in the pre-hospital setting, however, the pre-hospital team should accept higher rates of over-triage over under-triage, for the benefit of patients. In cases of doubt, the assessment by the emergency physician to activate the trauma team should be generally accepted.

Recommendations for pain therapy were already lacking in the last guideline. Unfortunately, due to the generous but still limited resources, it was not possible to amend this already detailed draft according to all methodological, structural, and substantive requirements. It is envisaged, however, that the draft text will first be published independent of the guideline. This will provide a systematic review, which can be both critically recognized and used as a guideline for individual management decisions, and then can be added to the consensus process of the update and thus be added to the next S3 guideline version.

Because of the challenging conditions of the prehospital emergency environment, the level of evidence is low, while experience and expertise are considerable. Numerous difficulties contribute here:

- Compliance with the standards of good clinical practice
- As a rule, patients are incapable of consent
- Heterogeneity of the patient population
- The difficulty of correctly and completely identifying, with limited diagnostic capabilities, the actual pattern of injury or pathophysiological processes (e.g. coagulopathy)
- Ethical concerns in omitting certain interventions in a comparison group (e.g. decompression of a tension pneumothorax)
- Doubts regarding transferability of results between differently organized rescue services

Nevertheless, it is necessary to translate evidence-based and expert recommendations into practical management recommendations and priority-driven processes. With the “Trauma Care Bundle” for pre-hospital management of severely injured patients, the German Trauma Society’s section on Emergency, Intensive care, and Injuries (section NIS) transferred key recommendations into a short and practical treatment guide, thus attempting to create a basis for improving quality of care [15]. There are also a variety of commercially available course formats, such as Prehospital Trauma Life Support® (PHTLS), International Trauma Life Support® (ITLS) or TraumaManagement®, which provide and distribute practical treatment protocols. The individual steps in these protocols conform to the key recommendations of the S3 guideline, but cannot be scientifically backed up in detail, as explained above. Thus, the present guideline did not aim to redevelop a similar concept. It should be emphasized here that all of these management interventions must be physically practiced and trained within the team. Within the “pre-hospital” section of the guideline, the current state of knowledge was accepted without much disagreement by the expert representatives, and high levels of agreement were attained. At the same time, the available knowledge remains incomplete in many areas, which is why consensus is often shaped by expert opinions. For this reason, the “new” recommendation grading system of GPP (Good Clinical Practice Points) was introduced for recommendations for which there is not evaluable evidence, but are considered important enough to make a recommendation. We hope that knowledge deficits and gaps, or recommendations that are not accepted universally, will inspire efforts to close these gaps, at least partially, with solid scientific research leading up to the next revision of the S3 guideline. We expressly encourage all interested parties to take on this important task [4].

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1.2 Airway Management, Ventilation, and Emergency Anesthesia

Preamble

Endotracheal intubation and ventilation, and thus definitive airway protection aimed at optimized oxygenation and ventilation, are central therapeutic measures in emergency medicine [146]. This is about securing the basic vital functions directly associated with survival. In established standards of trauma care, the “A” for airway and “B” for breathing are given the highest priority and thus, are particularly important for both pre-hospital and early hospital management [4, 131, 183].

One problem with evaluating the evidence available is that information cannot be directly referred to the German rescue and emergency physician system, due to the divergent organization of emergency rescue services internationally and the resulting differences in experience and routines used to secure the airway. This applies particularly for negative results from paramedic systems [102, 157]. Although paramedics are often employed in the Anglo-American region, the emergency physician system is widely used in continental Europe. But even here there is variation. In Germany, (specialist) physicians from all disciplines can participate in emergency services after acquiring the appropriate qualification, but in Scandinavian countries, this is mainly reserved for anesthesiologists [14]. As a consequence, the evaluation of international studies regarding pre-hospital securing of the airway reveals emergency medical personnel with very different levels of training. Depending on the personnel employed and how commonly they perform intubation, high rates of unsuccessful intubations are found in the literature, with 15 to 31%. Esophageal intubations occur in up to 12% of cases [38, 174]. Within paramedic systems, there is a higher rate of guideline non-compliant airway management [64]. For the emergency physician system in Germany, the stipulated minimum "Additional qualification in emergency medicine" and the use of emergency anesthesia produce a different scenario than that in the Anglo-American paramedic system, in which securing the airway is sometimes attempted without medications.

For the key recommendations to come, the following features of the pre-hospital care setting, which influence the development of indications to perform emergency anesthesia, intubation and ventilation, must be considered:

- Level of experience and the routine training of the emergency physician
- Circumstances of the medical emergency (e.g., patient is trapped, rescue time)
- Type of transport (land-based versus air-supported)
- Transport time
- Concomitant injuries of the airway region and any (recognizable) impediments to intubation

Depending on the individual case, the decision to perform or not perform pre-hospital anesthesia, intubation/airway management, and ventilation ranges between the extremes of "advanced training level, long transport time, simple airway," and "minimal experience, shorter transport time, predicted difficult airway." In any event, sufficient oxygenation must be secured using appropriate measures.

The following recommendations cover the overall topics of emergency anesthesia, airway management, and ventilation in the pre-hospital phase and in the Emergency Department.

Key Recommendations:

1.1	**Recommendation**	**2016**
GoR A	**For multiply injured patients with apnea or agonal breathing (respiration rate <6), emergency anesthesia, endotracheal intubation and ventilation must be performed in the pre-hospital setting.**	
1.2	**Recommendation**	**Modified 2016**
GoR B	**For multiply injured patients, emergency anesthesia, endotracheal intubation and ventilation should be performed in the pre-hospital setting for the following indications:** **• Hypoxia (SpO2 < 90 %) despite oxygen administration and after tension pneumothorax is excluded** **• Severe TBI (GCS < 9)** **• Trauma-associated persistent hemodynamic instability (SBP < 90 mmHg, age adapted for children)** **• Severe chest trauma with respiratory insufficiency (respiration rate > 29, age-adapted for children)**	
1.3	**Recommendation**	**2016**
GoR A	**Multiply injured patients must be pre-oxygenated before anesthesia induction.**	
1.4	**Recommendation**	**Modified 2016**
GoR A	**During in-hospital emergency anesthesia, endotracheal intubation and ventilation must be performed by trained and experienced anesthesia staff.** **When complicated in-hospital induction and/or endotracheal intubation is expected, an anesthesiologist must perform the procedure.**	

Explanation:

Indications for Intubation

Severe polytrauma has serious effects on the integrity of the human body. In addition to the acute consequences of trauma on individual body regions, there is a mediator-mediated whole-body reaction, i.e. Systemic Inflammatory Response Syndrome (SIRS) [48, 93]. Tissue oxygenation takes on special significance in this damage cascade. Tissue oxygenation can only be achieved if oxygen uptake, transport and release are maintained. Oxygen uptake is only possible with a free airway. Direct consequences of trauma (e.g. facial fractures, laryngeal injuries or obstruction due to blood, vomit and/or secretions), but also inability to keep the airway open independently because of loss of consciousness, can make securing the airway necessary. Endotracheal intubation is the gold standard for definitive airway protection according to current European and non-European guidelines [56, 130, 131]. Treatment recommendations of the German Society of Anesthesiology and Intensive Care Medicine (*Deutschen Gesellschaft für Anästhesiologie und Intensivmedizin*) and the S1

Guideline (AWMF) also support the indications for airway management listed above in the Key Recommendations [19].

Severe impairment of consciousness with a Glasgow Coma Score (GCS) < 9 due to a traumatic brain injury is regarded as an indication for intubation [12]. For the trauma patient with impairedconsciousness GCS ≤ 8, endotracheal intubation in both pre-hospital and hospital settings is also recommended in the guideline of the Eastern Association for the Surgery of Trauma (EAST) [56] and other training programs (e.g., ATLS® [4], ETC [70]). Hypoxia and hypotension are the "lethal duo" inducing secondary damage particularly in polytrauma patients with traumatic brain injury [36, 37, 90, 155, 158]. Abnormal brain computed tomography (38%) and intracranial bleeding (28%) have been reported even in patients with GCS of 13 or 14 who were endotracheally intubated in the pre-hospital phase [61]. In a pre-hospital cohort study, endotracheal intubation had a positive effect on survival following severe traumatic brain injury [96]. A comparative registry database study, which due to a number of factors is not comparable to the German emergency physician system, found a higher mortality for patients with a GCS of 3 who were intubated in the pre-hospital setting (Odds Ratio [OR] 1.93; 95 % CI: 1.74–2.15, p < 0.0001) [88]. However, in the post-hoc subgroup analysis by the Resuscitation Outcome Consortium (ROC) Hypertonic Saline (HS) trials (RCT) [173], which looked at data from two randomized clinical studies using hypertonic infusions, there was no increased 28-day mortality in TBI patients intubated in the pre-hospital setting versus those intubated in the Emergency Department (OR 1.57; 95% CI: 0.93–2.64). This study is also not transferable to the German emergency physician system for numerous reasons. There was increased 28-day mortality for patients in shock (SBP < 70 mmHg or SBP 71-90 mmHg + HR > 108 bpm) who had been intubated in the pre-hospital setting (OR 5.14; 95% CI: 2.42–10.90). Limitations in the interpretations of the secondary analysis of the ROC HS trial [173] include the pre-hospital paramedic system, the lack of data regarding the type of airway/anesthetic management, and the fact that muscle relaxants were used in only 70% of cases. Another retrospective study showed reduced mortality for children with severe TBI who were intubated by emergency physicians in the pre-hospital phase versus those receiving Basic Life Support (BLS) and delayed intubation in regional trauma centers [159]. Limiting consideration to the pediatric population, pre-hospital intubation was carried out by emergency medical physicians in this study, meaning good transferability to the German emergency physician system. Using the Trauma and Injury Severity Score (TRISS), another study also confirmed that pre-hospital intubation yields improved survival and neurologic outcomes [63]. Another paper showed improvements in the measured systolic blood pressure, oxygen saturation, and end-tidal carbon dioxide (etCO2) compared to baseline values prior to pre-hospital intubation in patients with severe TBI [16]. A methodically weaker retrospective analysis in a paramedic system showed no survival advantage for patients with TBI [30]. Regarding the time point of intubation in patients with traumatic brain injury and decreased level of consciousness, important results can be found in a prospective randomized controlled trial (RCT) in which intubation was performed by paramedics with a standard rapid sequence induction (RSI) protocol (fentanyl 0.1 mg + midazolam 0.1 mg/kg + succinylcholine 1.5 mg/kg) in patients with GCS < 10 (intubation success rate of 97%) compared to cases intubated by physicians on arrival to the hospital [17]. Using the extended Glasgow Outcome Scale (eGOS), patients undergoing pre-hospital intubation had better neurological outcomes after six months [eGOS 5-8 (n = 157 vs. n = 142): 51% vs. 39% with RR 1.28; 95% CI: 1.00-1.64, p = 0.046] than those managed in-hospital [17]. However, duration of intensive care and hospital admissions as well as survival until discharge did not differ [17]. A comparative registry database study also supports the recommended indications for intubation in TBI listed above, particularly for severely affected patients [47]. A retrospective cohort study of comparable patient groups (ISS 10 vs. 11) reported that delayed endotracheal intubation (n = 34, intubation 24 min) was associated with higher mortality than earlier intubation (n = 56, intubation 10-24 min) after admission to the Emergency Department (11.8 % vs. 1.8 %, p = 0.045) [112]. The authors calculated a relative risk reduction of 85 % for mortality when the patient airway was secured early (i.e., within 10-24 min) on admission to the hospital.

Current review studies include heterogeneous patient populations, various types of emergency medical services, as well as differing levels of experience for the care providers and thus, do not always yield positive results for intubation [14, 22, 45, 53, 102, 104, 124, 131, 172, 175] The EAST guideline group also addressed this problem. In the "Guidelines for Emergency Intubation Immediately Following Traumatic Injury," it was stated that there are no randomized controlled trials on this research question. On the other hand, however, the authors of the EAST Guideline also found no studies presenting a proven alternative treatment strategy. In summary, endotracheal intubation was assessed overall as such an established procedure in hypoxia/apnea that, despite a lack of scientific evidence, a Grade A recommendation was formulated [56].

Other conditions requiring a definitive airway are gas exchange disturbances, even when the native airway is open. A current investigation on airway protection in moderately injured patients supports apnea as an indication for intubation [85]. Other indications for endotracheal intubation (e.g. chest trauma) are disputed in the literature [141]. Hypoxia and respiratory failure have been established as consequences of severe chest trauma (multiple rib fractures, lung contusion, flail chest). If hypoxia is refractory to oxygen administration, exclusion of tension pneumothorax, and basic measures of airway support, endotracheal intubation is recommended [56]. Pre-hospital endotracheal intubation in patients with severe thoracic trauma can prevent hypoxia and hypoventilation, which are associated with secondary neurologic damage and severe repercussions on the rest of the body. However, with difficult, prolonged attempts at intubation and the associated hypoventilation and risk of hypoxia, endotracheal intubation itself can cause procedure-associated secondary damage or even death. A database analysis of the Trauma Registry of the German Trauma Society showed no advantage in prehospital endotracheal intubation in patients suffering chest trauma without respiratory insufficiency [141]. Severe chest injury with respiratory insufficiency does present an indication for prehospital endotracheal intubation; however, the decision to intubate should be made based on respiratory insufficiency and not the (suspected) diagnosis of severe chest injury, which is associated with a degree of uncertainty [10].

Endotracheal intubation is included as an "Advanced Life Support" procedure in the pre-hospital action algorithms of various training programs (e.g., PHTLS®, ETC) [70, 126]. In this context, studies have been conducted to examine compliance with these recommendations. Using a scoring system to evaluate management problems along with the relevant autopsy reports, a series of fatal traffic accidents were retrospectively analyzed to characterize the effectiveness of pre-hospital care and potentially avoidable mortality [136]. Here factors leading to avoidable death included prolonged "pre-hospital and early in-hospital care period" as well as "lack of airway protection with intubation" [136].

Considering the cases presented in the Preamble, the following aspects have particular relevance. A retrospective cohort study of 570 intubated patients versus 8137 non-intubated patients reported that patients intubated pre-hospital had pre-hospital times lasting 5.2-10.7 minutes longer than that of non-intubated patients [43]. A prospective non-randomized study assessed the influence of early intubation within two hours of trauma on subsequent organ failure [169]. Despite a significantly higher degree of injury in the group of patients who were intubated "early" (within 2 hours of trauma), the incidence of organ failure and mortality were decreased compared to those intubated "later." A retrospective trauma registry database study compared 3571 patients intubated pre-hospital to 746 patients intubated in the Emergency Department and 11 586 patients who were not intubated at all [7]. Intubation performed in the Emergency Department was associated with significantly higher mortality risk compared to non-intubated patients (OR 3.1; 95% CI: 2.1-4.5, $p < 0.0001$) and patients intubated in the pre-hospital setting (OR 3.0; 95 % CI: 1.9–4.9, $p < 0.0001$) [7]. It should also be noted that patients intubated in the pre-hospital setting did not have a higher mortality risk than patients who were not intubated in the Emergency Department (OR 1.1; 95 % CI: 0.7–1.9; $p = 0.6$). The authors concluded that patients who weren't intubated before arriving in the Emergency Department should have been intubated in the pre-hospital setting [7]. Thus, when choosing the optimal time point for anesthetic induction and endotracheal intubation, one must consider the pattern of injury, the personal experience of the emergency physician/anesthesiologist, the ambient environment, the time needed for transfer, the equipment available, and the procedure-related complications. With these points in mind, for definitive care, the polytrauma patient must undergo emergency anesthesia with endotracheal intubation and ventilation. Endotracheal intubation must be carried out for appropriate indications and corresponding level of training in the pre-hospital setting, or at the latest in the Emergency Department. According to an analysis of the German Trauma Society's trauma registry database, of 24 771 patients, 31% unconscious at the accident scene (GCS < 9), 19% showed severe hemodynamic instability (SBP $<$ 90 mmHg), and 55% were intubated by the emergency physician in the pre-hospital setting [140]. According to this analysis, 9% of polytrauma patients' time in the Emergency Department was cut short for a necessary emergency intervention, 77% of the polytrauma patients eventually underwent an operative intervention, and 87% were in intensive care [140]. A large number of polytrauma patients require intensive care ventilation and invasive ventilation therapy because of traumatic brain injury and/or chest trauma, and all require adequate pain therapy. In the study mentioned above, the mean duration of ventilation for polytrauma patients was nine days [140].

To prevent damaging effects like hypoxia and hypoventilation, emergency anesthesia, intubation, and ventilation must be performed in the pre-hospital setting or at the latest in the Emergency Department when the corresponding indications are present and the provider has an appropriate level of training. A large retrospective study using the trauma registry of a Level I trauma center evaluated 6088 patients in whom endotracheal intubation had been performed within the first hour of hospital admission [156]. According to this trauma registry, an additional 26 000 trauma patients were intubated on the day of hospital admission after the first hour of hospital care. As shown in this hospital study, in the hands of experienced anesthesiologists, rapid sequence induction is an effective and safe procedure. No patients died during intubation. Of 6088 patients, 6008 were successfully intubated orotracheally (98.7%), and a further 59 nasotracheally (0.97%). Only 17 patients (0.28%) needed cricothyroidotomy and 4 patients (0.07%) underwent emergency tracheotomy. Three other patients later required emergency tracheotomy after endotracheal intubation [156]. Another retrospective study of a monocenter trauma registry studied 1000 trauma patients (9.9% of 10 137 patients) who had been endotracheally intubated within 2 hours of admission to the trauma center [153]. At $< 1\%$, the incidence of surgical airway placement was also uncommon. Aspiration occurred in 1.1% of intubations. Early intubation was also considered safe and effective by the authors [153]. These data also confirm that endotracheal intubation of trauma patients is a safe procedure in the hands of anesthesiologists. Another retrospective study from a paramedic-supported system showed a success rate of 96.6% and a markedly higher cricothyroidotomy rate of 2.3% in 175 endotracheally intubated patients [62]. In 1.1% of cases, patients were ventilated by bag-valve-mask during transfer to hospital. There were five cases of right endobronchial intubation (2.9%) and two cases of tube displacement (1.1%). There were no documented cases of failed intubation. In pre-hospital emergency medicine, intubation success varies among various provider types and physicians of various specialties [72]. An observational study of 7259 trauma patients examining failed intubation found significant differences between anesthesiologists and non-anesthesiologists performing the procedure (11/2587, 0.4 % vs. 41/4394, 0.9 %, $p = 0.02$) [105]. In the pre-hospital as well as in-hospital settings, the most experienced provider must secure the airway. In-hospital, this is generally an anesthesiologist [38].

In a pre-hospital cohort study with comparable injury severity (ISS 23 versus 24) and similar duration of care (27 versus 29 min, $p = 0.41$), 60 patients were treated by emergency services personnel (emergency medical technician [EMT], intubation rate 3%) and 64 patients in Advanced Life Support mode by emergency physicians (intubation rate 100%). For the patients treated by emergency physicians, oxygen saturation was significantly improved upon hospital arrival (SaO2: 86% versus 96%; $p = 0.04$) and systolic blood pressure was significantly higher (105 versus 132 mmHg, $p = 0.03$). Overall mortality did not vary between the groups (42 % vs. 40 %, $p = 0.76$). However, sub-group analysis showed a significant survival advantage for those patients with GCS between 6 and 8 treated by an emergency physician (Mortality: 78 versus 24%, $p < 0.01$; OR 3.85, 95% CI: 1.84–6.38, $p < 0.001$). The authors concluded that mortality is reduced by a pre-hospital emergency physician system offering rapid sequence induction, sufficient oxygenation, and hemodynamic drug therapy, particularly for patients with decreased levels of consciousness [96].

One point of criticism regarding pre-hospital endotracheal intubation and the associated emergency anesthesia is a theorized loss of time. In fact, an analysis of patients with ISS ≥ 16 in the German Trauma Society database found that endotracheal intubation at the accident scene is associated with an average pre-hospital time increase of 9 ± 1 min [184]. However, this does not necessarily reflect a disadvantage regarding the entire treatment time for patients from trauma to end of Emergency Department care. Another comparative study of the German Trauma Society's trauma registry over the years 2002-2007 performed by Kulla et al. [99] stratified the patients into three groups: Group AA (n = 963, pre-hospital intubation and chest tube placement), group AB (n = 1547; pre-hospital intubation and in-hospital chest tube placement), and group BB (n = 640; in-hospital intubation and chest tube placement). While the pre-hospital care times of all groups differed (time of trauma until hospital arrival: 80 ± 37 vs. 77 ± 44 vs. 64 ± 46 min), there was no difference in overall treatment time (time of trauma until end of Emergency Department care: 152 ± 59 vs. 151 ± 62 vs. 148 ± 68 min). This study makes clear that in cases where pre-hospital (indicated) interventions are postponed, although the time to Emergency Department arrival is decreased (while life-threatening risks persist), the saved time is lost again during the Emergency Department care phase. Thus, no overall time benefit (pre-hospital phase + Emergency Department phase) is produced. For this reason, indicated pre-hospital and potentially life-saving interventions (e.g., endotracheal intubation, chest tube placement) should also be performed in the pre-hospital phase [99].

In the German-speaking emergency physician system, pediatric and adult emergency patients are endotracheally intubated with very high success rates when the procedure is carried out by experienced and trained personnel. In a prospective study over a period of 8 years, 4% of all pediatric emergency patients (82 of 2040 children) were endotracheally intubated [60]. Pediatric calls accounted for 5.6% of all emergency calls (2040 out of 36 677 physician ambulance calls). Anesthesiologists performed 58 of the pediatric endotracheal intubations, with a success rate of 98.3%. Based on the incidence, the known number of emergency physicians employed per year, and their absolute number of ambulance calls, each emergency physician in the emergency physician service has an average gap of 3 years between pediatric intubations and 13 years between infant intubations. These results show that endotracheal intubation in childhood is rare outside of the hospital setting, and thus, special attention must be paid to maintaining expertise and appropriate training outside the emergency services and emergency physician service.

A prospective study of 16 559 patients treated in the pre-hospital setting included 2850 trauma patients of whom 259 (9.1%) were endotracheally intubated. More than two attempts were required in 3.9% of cases before endotracheal intubation was successful, and intubation failed in 3.9% of cases. A difficult airway was reported in 18.2% of cases. In comparison, a difficult airway was reported in only 16.7% of patients with cardiac arrest. In this study as well, anesthesiologists working as emergency physicians showed a success rate of 98.0% [165]. Another prospective study of 598 patients (of these, 10% trauma patients) in an emergency physician system showed a success rate of 98.5% [162]. Another prospective study reported a success rate of 100% in a collective of 342 patients [n = 235 (68.7%) trauma patients] when anesthesiologists working in the emergency services performed the intubations. In this case, the first attempt was successful in 87.4% of cases, the second attempt in 11.1% and the third attempt in 1.5% [78]. Another study of the German emergency physician system showed a prehospital endotracheal intubation success rate of 97.9% in trauma patients [2].

In a retrospective cohort study of 194 patients with traumatic brain injury, the mortality of patients treated with basic life support (BLS) by the land-based emergency services differed significantly from that of patients treated with advanced life support (ALS) by anesthesiologists in the air-supported emergency services (25 versus 21 %, $p < 0.05$). In this study, the survival rate of patients with TBI treated with significantly more invasive measures by the air rescue group (intubation 92 versus 36%, chest tubes 5 versus 0%) was better than that of patients treated by the land-based emergency services (54 versus 44%, $p < 0.05$) [15].

Procedure-Related Complications

Regarding procedure-related complications, a retrospective trauma registry database study found no higher risk of pneumonia in 271 or 357 patients intubated in the respective pre-hospital or in-hospital settings [167]. Regarding epidemiological data, patients intubated pre-hospital showed lower GCS (4 versus 8, $p < 0.001$) and higher injury severity scores (ISS 25 versus 22, $p < 0.007$), but otherwise no differences. Nevertheless, although expected, length of hospital stay for both patient collectives (15.7 versus 15.8 d), length of intensive care stay (7.6 versus 7.3 d), number of days on a ventilator (7.8 versus 7.2 d), mortality rates (31.7 versus 28.2%), and resistant bacteria rates (46% in each case) did not vary. On average, it took 3 days until the onset of pneumonia in both groups, and the pneumonia rate was also comparable in both groups [167]. Another study did report a significantly increased rate of pneumonia following pre-hospital versus in-hospital intubation [154]. However, this had no influence on the 30-day mortality rate and the number of days in intensive care. Moreover, the group of patients intubated pre-hospital had increased injury severity. In another study, frequency of pulmonary complications was related to injury severity but not to intubation mishaps [152]. A post hoc sub-group analysis of data from the Resuscitation Outcomes Consortium (ROC) Hypertonic Saline trial with 1676 patients (inclusion criteria: age > 14 years, SBP < 70 mmHg or 71-91 mmHg with HR > 107bpm or GCS < 9; survival > 24 hours) evaluated the association between intubation timeframe and rate of pneumonia [6]. The overall rate of pneumonia was 22% [6]. Compared to patients without an invasive airway, patients intubated pre-hospital had a 6.8-fold increased adjusted risk (95% CI: 2.0-23.0, p = 0.003) for developing pneumonia after the 2nd-4th hospital day (defined as the index time point for an external airway-associated pneumonia); Patients receiving an invasive airway in-hospital had a 4.8-fold increased adjusted risk (95% CI: 1.4-1.6, p = 0.01) [6]. Pre-hospital versus in-hospital airway management showed no significant difference. The authors concluded that invasive airway management itself increases the risk for pneumonia. However, a correlation between pre-hospital endotracheal intubation and the occurrence of pulmonary complications could not be reliably confirmed. Given the limited methodology of the study and the low case number, the results must be interpreted with caution.

In a retrospective study of 244 patients intubated in the prehospital phase by an emergency physician, desaturation with an $SpO2 < 90\%$ was documented in 18% of cases, and hypotension with systolic blood pressure < 90 mmHg in 13% of cases. The two complications did not occur in parallel for any of the cases [129].

Matched-pair analysis was used to evaluate the effects of endotracheal intubation performed in the pre-hospital setting, using the German Trauma Society's trauma registry database over the years 2005 to 2008 [85]. In this analysis, moderately injured patients were selected (> 16 years, AIS < 4, GCS 13-15, no pRBC transfusion). Owing to the inclusion criteria, it appears, at least after the fact, that the authors endorsed relatively minor needs for invasive airway management. These patients were matched with comparable cases who were treated without pre-hospital endotracheal intubation. Comparison of the two homogeneous groups showed that intubated patients differ significantly from non-intubated regarding longer pre-hospital time, increased volume replacement, and worse coagulation parameters on admission to the Emergency Department. In addition, intubated patients had higher rates of sepsis (not intubated 1.5% vs. intubated 3.7%; $p \leq 0.02$) and organ failure (not intubated 9.1% vs. intubated 23.4%;

$p \leq 0.001$). Regarding the harder treatment outcome "hospital mortality," however, the groups did not differ (intubated 0.5 vs. non-intubated 1.0%, $p = 0.32$). One weakness of this study is the retrospective design based on registry data, since it remains unclear what the pre-hospital indications for intubation were. Accurate determination of true severity of injury is often difficult in the pre-hospital setting [75, 122], and it is possible that the indications for intubation in the investigated cases later proved to be unnecessary, distorting the end results of the study. In cases of doubt, it is advisable to favor pre-hospital intubation if it is indicated by the airway evaluation or the suspected pattern of injury, since there is no difference in hospital mortality. The basic prerequisite for this is that the provider is proficient with the procedure. In any case, however, like in any therapy, the potential complications and consequences must be weighed against the potential benefits. The available data speak in favor of intubation for the indications given in the key recommendations, and of critical consideration for others.

The key recommendations of the current S3 guideline on indications for pre-hospital airway protection correspond to those in the Treatment Recommendations for Pre-Hospital Emergency Anesthesia in Adults by the German Society of Anesthesiology and Intensive Care Medicine as well as of the S1 Guideline (AWMF) by the same name [19].

Pre-Oxygenation

To avoid drops in oxygen saturation during anesthetic induction and endotracheal intubation, the spontaneously breathing polytrauma patient should, if feasible, be pre-oxygenated for up to 4 minutes with 100% oxygen via a face mask with reservoir [131]. In a non-randomized controlled study of 34 intensive-care patients, the mean paO2 at the onset of pre-oxygenation was (T0) 62 ± 15 mmHg, after 4 minutes (T4) 84 ± 52 mmHg, after 6 minutes (T6) 88 ± 49 mmHg, and after 8 minutes (T8) 93 ± 55 mmHg. The differences in paO2 were significantly different between T0 and T4–8, but not individually between T4, T6 and T8. In 24% of patients, there was even a PaO2 reduction between T4 and T8. A longer period of pre-oxygenation for 4 to 8 minutes did not lead to any marked improvement in arterial oxygen partial pressure and it delays securing the airway in critical patients [119, 120]. Thus, appropriately performed pre-oxygenation for 4 minutes has particular importance in securing the airway of polytrauma patients. The recommendations listed here correspond to those in the Treatment Recommendations for Pre-Hospital Emergency Anesthesia in Adults by the German Society of Anesthesiology and Intensive Care Medicine (*Deutschen Gesellschaft für Anästhesiologie und Intensivmedizin*) as well as of the S1 Guideline (AWMF) by the same name [19]. Pre-oxygenation by emergency personnel begins immediately after the decision to anesthetize/intubate, while anesthetic and emergency medications as well as equipment for airway support and ventilation are being prepared. Pre-oxygenation must be performed exclusively with 100% oxygen using a face mask or a tight-fitting bag-valve-mask, each with an oxygen reservoir (at least 12-15 L O2/min) or, even more effective, through use of a demand valve or by non-invasive ventilation (NIV) when contraindications are excluded [19]. Even with maximum oxygen flow, a facemask without a reservoir is not sufficient. One approach that can facilitate pre-oxygenation (particularly in non-cooperative patients) is the use of dissociative anesthesia by administration of ketamine (similar to "delayed sequence intubation) [182].

Education and Training

Key recommendation:

1.5	Recommendation	2016
GoR A	**Emergency personnel must be regularly trained in emergency anesthesia, endotracheal intubation, and alternative methods of airway protection (mask ventilation, laryngeal tube, cricothyrotomy).**	

Explanation:

In a recent survey of emergency physicians working in the emergency physician service, questions were posed regarding knowledge of and experience in endotracheal intubation and alternative methods for securing an airway [163]. This survey received responses from 340 anesthesiologists (56.1%) and 266 non-anesthesiologists. It found that all anesthesia-trained emergency physicians had performed more than 100 in-hospital endotracheal intubations compared to only 35% of non-anesthesiologists. A similar picture emerged for alternative methods of securing an airway. 97.8% of anesthesiologists-as-emergency physicians had used alternative methods of securing an airway on more than 20 occasions, while only 11.1% of non-anesthesiologist emergency physicians had equivalent experience ($p < 0.05$). In addition, it came out that only 27% of emergency equipment included CO2 monitoring (capnography). From this study, it can be concluded that there is an urgent need for training of non-anesthesiologist emergency physicians in endotracheal intubation, capnography, and alternative airway methods [131].

Studies on first-year anesthesiology residents have reported that more than 60 intubations are necessary to achieve a success rate of 90% within the first two attempts under standardized, optimum conditions in the operating room [98]. Another proficiency study of 20 non-anesthesiologist physicians performing endotracheal intubation on 438 patients for elective anesthesia found an increasing success rate and better vocal cord visualization up to the

35th intubation. An 80% success rate was observed after the 35th intubation, and 90% after the 47th [123]. The largest prospective monocenter study to date on the development of intubation proficiency of first year anesthesia residents (n = 21) showed progressive intubation success rates from the 25th to the 200th intubation for first pass intubation success (FPS: 67 vs. 83%, p = 0.0001) and overall intubation success (OPS: 82 vs. 92%, p = 0.0001) [20]. With an increasing number ofperformed intubations, the attempts required for success decreased (1.6 ± 0.8 vs. 1.3 ± 0.5, p = 0.0001). The investigation found that a trainee needs a range of approximately 100-150 intubation procedures performed to reach an overall success rate (OPS) of 95% [20]. There are no published studies to date reporting on the development of proficiency for endotracheal intubation under pre-hospital, Emergency Department, polytrauma, or severely injured in emergency situations. In clinical practice, only the most experienced providers perform airway support during these situations, and thus, the availability of such studies with inexperienced trainees can hardly be expected in the future. The evidence regarding proficiency during endotracheal intubation in well-observed and safe elective situations led to the key recommendation by the German Society of Anesthesia and Intensive Care Medicine that endotracheal intubation should only be carried out by providers who have performed at least 100 endotracheal intubations overall and perform 10 intubations per year [164]. Regarding proficiency of securing the airway with alternative methods, a prospective monocenter study of first year residents (n = 10) and 394 patients compared placement success rates for the ProSeal laryngeal mask for the first five insertions and the 40th insertion. The first pass success increased from 72 to 86% (p = 0.09) and overall success from 74 to 96% (p = 0.001) [113]. The evidence regarding proficiency during alternative airway management in well-observed and safe elective situations led to the key recommendation by the German Society of Anesthesia and Intensive Care Medicine that alternative airway placement should only be carried out as a primary procedure when the indications for endotracheal intubation listed above are not met or as a supraglottic alternative for a difficult airway, and by providers who have performed at least ten alternative airway placements overall and perform three alternative airway placements per year [164]. However, since the success of alternative methods for securing an airway (e.g., supraglottic airways: laryngeal mask, laryngeal tube) are only as good as the corresponding level of training for the procedure, and current evidence indicates that the appropriate level of training is not available everywhere [163], endotracheal intubation continues to be the gold standard. These findings also illustrate that emergency medical personnel must be regularly trained in endotracheal intubation as well as alternative airway management [131]. This is particularly important because the experience level of the person securing the airway is negatively correlated with patient mortality. A systematic review study and meta-analysis showed higher mortality rates for patients with TBI intubated by less experienced providers in the pre-hospital setting (OR 2.33; 95 %-CI: 1.61-3.38, p < 0.001). In cases where experienced providers performed pre-hospital intubation, there was no increased mortality (OR 0.75, 95% CI: 0.52-1.08, p = 0.126). Meta-regression identified experience in airway management as a significant predictor for mortality of these patients (p = 0.009) [25]. Regarding emergency crichothyrotomy, a retrospective cohort study for the years of 2007 to 2013 found that of 493 airway protection procedures performed by "ambulance nurses," a helicopter emergency physician detected and corrected failed intubation and hypoxia in 42% (8.5%) of cases [134]. For a further 1406 endotracheal intubations, there was a success rate of 98.4%. Seven patients were ventilated with bag-valve-mask ventilation (n = 2) and alternative airway support (n = 2); in 30 cases, surgical airway procedures (emergency crichothyrotomy n = 28 and tracheotomy n = 2) were performed; in three cases airway management was abandoned for non-survivable injuries. This data shows that a surgical airway is rarely necessary, but to perform it, the appropriate training is necessary and this measure can be life-saving [134].

In the literature, there are numerous references to standard operation procedures (SOPs) and checklists for anesthetic induction and airway management [114, 149]. The Treatment Recommendations of the German Society of Anesthesiology and Intensive Care Medicine offer a national proposal for a structured approach to emergency anesthesia [19].

Alternative Methods of Airway Management

Key Recommendations:

1.6	**Recommendation**	**2016**
GoR A	**A difficult airway must be anticipated when performing endotracheal intubation of the trauma patient.**	
1.7	**Recommendation**	**2016**
GoR A	**During anesthesia induction and endotracheal intubation of the polytrauma patient, alternative methods to secure the airway must be available.**	
1.8	**Recommendation**	**Modified 2016**
GoR A	**Fiberoptic equipment must be available for anesthesia induction and endotracheal intubation performed in-hospital.**	
1.9	**Recommendation**	**Modified 2016**
GoR A	**Alternative methods of ventilation and/or securing the airway must be considered after more than 2 attempts at intubation.**	

Explanation:
Because of the environmental factors, endotracheal intubation of emergency patients in the pre-hospital setting is significantly more difficult than in-hospital. Thus, a difficult airway must always be anticipated when endotracheally intubating a trauma patient [131]. In a large study of 6088 trauma patients, risk factors and impediments to endotracheal intubation were foreign bodies in the pharynx or larynx, direct injuries to the head or neck with loss of normal upper airway anatomy, airway edema, pharyngeal tumors, laryngospasm, and difficult pre-existing anatomy [156]. In another study, a difficult airway was present more frequently in trauma patients (18.2%) than e.g., patients with cardiac arrest (16.7%) and particularly patients with other diseases (9.8%). Reasons given for difficult airway management were patient position (48.8% of cases), difficult laryngoscopy (42.7% of cases), secretions or aspiration in the oropharynx (15.9% of cases), and traumatic injuries (including bleeding/burns) in 13.4% of cases [165]. Technical problems occurred in 4.3% and other causes in 7.3% of cases. Further studies show similar statistics for difficult intubation (blood 19.9%, vomit 15.8%, hypersalivation 13.8%, anatomy 11.7%, trauma-induced anatomical changes 4.4%, patient position 9.4%, lighting conditions 9.1%, technical problems 2.9%) [78]. In a prospective study of 598 patients, adverse events and complications occurred significantly more often in patients with severe injuries than non-traumatized patients ($p = 0.001$) [162]. At least one event was documented in 31.1% of traumatized patients. The number of attempts required for intubation was also significantly increased in trauma patients ($p = 0.007$) [162]. Patients with severe maxillofacial trauma in particular show increased risk for difficult intubation (OR 1.9, 95% CI: 1.0–3.9, $p = 0.05$) [41]. In fact, maxillofacial trauma represents an independent risk factor for difficult airway management (OR 2.1, 95% CI: 1.1–4.4, $p = 0.038$). A retrospective analysis of a trauma registry over seven years identified 90 patients with severe maxillofacial injuries. Of these, 93% initially received definitive airway protection, by means of endotracheal tube in 80% of cases and through a surgical airway in 15% [39]. Based on this data, the presence of blood, vomit or other fluids in the oropharynx is to be expected, and with it, a difficult intubation. The patient should also be assumed to be non-fasting. A high-performance suction unit must therefore be available as a matter of course. Because of structural and procedural considerations of the pre-hospital setting, back-up with an experienced anesthesiologist often isn't possible. In-hospital, however, the standard is for an anesthesiologist to participate in the anesthesia and intubation of patients expected to be difficult. A prospective cohort study found that the presence of an attending anesthesiologist at in-hospital emergency intubations resulted in significantly fewer complications (6.1 versus 21.7%, $p < 0.0001$) [147]. However, there was no difference in the number of ventilator-free days or the 30-day mortality rate.

If endotracheal airway protection fails, oxygenation must be ensured using an appropriate algorithm to revert to bag-valve-mask ventilation and/or alternative methods of airway management [5, 27, 79, 130, 131]. Treatment Recommendations for Pre-hospital Airway Management by the German Society of Anesthesiology and Intensive Care Medicine and the Treatment Recommendations for Pre-Hospital Emergency Anesthesia in Adults suggest readiness and implementation of alternative methods for airway protection [19] [164]. In a prospective study, intubation success was evaluated in 598 patients in an emergency physician system staffed solely by anesthesiologists. Endotracheal intubation was successful at the first attempt in 85.4% of all patients, and the second attempt in 10.4%. Only 2.7% required more than two attempts; in 1.5% ($n = 9$), alternative methods such as the supralaryngeal combitube ($n = 7$), laryngeal mask ($n = 1$) or an emergency cricothyroidotomy ($n = 1$) were used after the third unsuccessful intubation attempt [162]. The study illustrates that alternative airway protection methods must be provided even in highly professional systems [94].

The success of endotracheal intubation on the first pass (FPS) has relevant effects on patient morbidity [18]. When multiple intubation attempts are necessary, the complication risk increases markedly (multiple attempts at intubation, MAI > 1: 4-fold complication rate, MAI > 2: 4.5 - 7.5-fold complication rate). The success of the first intubation attempt and the occurrence of multiple attempts depends on the experience of the provider [18]. In a retrospective study of 2833 patients intubated in-hospital at a Level I trauma center, the risk of airway-associated complications was markedly increased with more than 2 intubation attempts: hypoxemia 11.8 vs. 70%, regurgitation 1.9 vs. 22%, aspiration 0.8 vs. 13%, bradycardia 1.6 vs. 21%, cardiac arrest 0.7 vs. 11% [117]. Another prospective, multicenter study examined the number of intubation attempts (through the oropharynx) necessary for successful endotracheal intubation in emergency patients over an 18-month period [176]. Endotracheal intubation was carried out by paramedics in 94% of cases and by nurses or emergency physicians in the remaining 6%. Overall, 1941 intubations were carried out, of which 1272 (65.5%) occurred in patients with cardiac arrest, 463 (23.9%) were performed without drug administration in patients without cardiac arrest, 126 (6.5%) occurred under sedation in patients without cardiac arrest, and 80 (4.1%) took place by rapid sequence induction using a hypnotic agent and a muscle relaxant. Over 30% of patients required more than one attempt to achieve successful endotracheal intubation.

More than 6 intubation attempts were not reported in any case. The cumulative success rates during the first, second and third intubation attempts were 70%, 85% and 90% in patients in cardiac arrest. This was markedly higher than in the other 3 patient subgroups with intact circulatory function (intubation without drugs: 58%, 69% and 73%; intubation under sedation: 44%, 63% and 75%; intubation with rapid sequence induction: 56%, 81% and 91%). The specific success rates were not further differentiated according to provider type (paramedics, nurses and emergency physicians). The results of this study [176] show that the cumulative success rate of endotracheal intubation in a paramedic system is markedly below that of emergency physician systems staffed solely by anesthesiologists, with rates of 97-100% [78, 162, 165]. In addition, the use of medications, e.g. those used in rapid sequence induction (including muscle relaxants), helps facilitate intubation in patients without cardiac arrest and thus leads to a markedly higher success rates. Both are often crucial to survival during an emergency situation. According to the above-cited study and other study results [18, 55, 73, 74, 95, 109, 117, 138], alternative methods must be considered to secure an airway after two unsuccessful intubation attempts [5, 117]. In particular, it must be considered that the intubation success rate after the second attempt by inexperienced providers is $< 1\%$ in elective anesthesia [20]. Thus, the current key recommendation of this S3 Guideline corresponds to the S1 Guideline Airway Management by the German Society of Anesthesiology and Intensive Care Medicine, which states that intubation attempts with direct laryngoscopy should be limited to a maximum of two [135]. Although fiberoptic procedures are infrequently available in the prehospital setting, fiberoptic intubation must be available as part of hospital anesthesia equipment according to the specifications of the S1 "Airway Management" Guideline of the German Society of Anesthesiology and Intensive Care Medicine [135]. With appropriate experience and conditions, fiberoptic (conscious) intubation, preserving spontaneous respiration, is considered an alternative for emergency airway management by all common guidelines and recommendations [57, 76, 79, 101].

In contrast, emergency cricothyroidotomy is simply the last resort in a "cannot ventilate - cannot intubate" situation to secure emergency ventilation and oxygenation. In national and international recommendations and guidelines, emergency cricothyroidotomy has a firm place in the prehospital and hospital settings and is indicated if alternative methods for securing an airway and bag-valve-mask ventilation are not successful [14, 76, 79, 125].

Monitoring Emergency Anesthesia

Key recommendation:

1.10	Recommendation	2016
GoR A	**ECG, blood pressure, pulse oximetry, and capnography must be monitored during anesthesia induction, endotracheal intubation, and emergency anesthesia.**	

Explanation:
The German Society of Anesthesiology and Intensive Care Medicine (DGAI) specifies certain requirements for a "standard workplace" in its update to the guideline on equipping anesthesia work areas [49, 135]. Special attention must be paid to the often difficult environment (e.g., confined space, unfavorable lighting, limited resources) in the pre-hospital emergency setting and particularly in trauma care. The complication rate in emergency anesthesia induction, airway insertion, and ventilation is not to be underestimated and according to results of prospective observational studies and prospective multicenter registry studies is something between 11-13% [32, 127, 139]. Obesity, poor vocal cord visualization (Cormack/Lehane III/IV), and difficult intubation situations are particularly associated with complications in pre-hospital airway management [32].

According to the S1 guideline and Treatment Recommendations for Pre-hospital Emergency Anesthesia in Adults of the German Society of Anesthesiology and Intensive Care Medicine, the following equipment should be available for the procedure and monitoring of emergency anesthesia in the pre-hospital setting [19, 131]: electrocardiogram (ECG), non-invasive blood pressure monitoring, pulse oximetry, capnography/capnometry, defibrillator, emergency respirator and suction unit. Appropriate equipment must be provided based on the guideline "Airway Management" of the German Society of Anesthesiology and Intensive Care Medicine [27] as well as the German DIN standards for emergency physician vehicles (NEF) [52], rescue helicopter (RTH) [50] and ambulance (RTW) [51].
In-hospital, the directives of the DGAI must be followed in the emergency room and in the other hospital wards [49, 135].

Emergency Ventilation and Capnography

Key Recommendations:

1.11	Recommendation	Modified 2016
GoR A	**Capnometry/capnography must be used pre-hospital and in-hospital during endotracheal intubation to control tube placement and afterwards, to monitor displacement and/orventilation.**	

1.12	**Recommendation**	**2016**
GoR A	**Normoventilation must be carried out for endotracheally intubated and anesthetized trauma patients.**	
1.13	**Recommendation**	**2016**
GoR A	**Beginning in the Emergency Department, ventilation must be monitored and controlled with frequent arterial blood gas analyses.**	

Explanation:

In the pre-hospital and in-hospital phases, capnometry/capnography must always be used during endotracheal intubation for monitoring tube placement and afterwards to reduce displacement and monitor ventilation. Capnography is an essential component here in monitoring the intubated and ventilated patient [131]. Normoventilation must be carried out for endotracheally intubated and anesthetized trauma patients. Beginning in the Emergency Department, ventilation must be monitored and controlled with frequent arterial blood gas analyses.

Capnography as Monitor of Tube Position/Displacement

The most serious complication of endotracheal intubation is an unrecognized esophageal intubation, which can lead to patient death. For this reason, every alternative must be used, in both pre-hospital and hospital settings, to recognize esophageal intubation and remedy it immediately.

The range of esophageal intubation rates reported in the literature begins at less than 1% [175, 181] goes through 2% [65] and 6% [133], and reaches almost 17% [92]. In addition, high mortality was shown as a result of tube misplacement in the hypopharynx (33%) or in the esophagus (56%) [92]. Thus, esophageal intubation is not such a rare event. Especially recently, various studies have examined this catastrophic complication of endotracheal intubation also in Germany. In a prospective observational study, helicopter anesthesiologists-as-emergency physicians identified esophageal tube placement in 6 (7.1%) and endobronchial tube placement in 11 (13.1%) of 84 trauma patients intubated by land-based emergency physicians before helicopter arrival [166]. In this study, the mortality rate for esophageally intubated patients was 80%. Another prospective study of 598 patients within the German emergency physician system found a rate of esophageal intubations by non-medical personnel or non-emergency physicians before arrival of the emergency physician system of 3.2% [162]. One more prospective observational study reported esophageal intubation in 5.1% of 58 patients intubated by the land-based emergency service or emergency physician before arrival of the helicopter emergency physician (anesthesiologist) [68]. In another study, the admitting trauma team in the Emergency Department identified esophageal intubation in 4 out of 375 (1.1%) patients intubated and ventilated in the pre-hospital setting [66].

A prospective observational study of 153 patients found no misplaced intubation in patients monitored with capnography, but in 14 of 60 unmonitored (with capnography) patients (23.3%) [151]. Capnography thus belongs in the standard anesthesia equipment and has dramatically increased anesthesia safety.

In a prospective observational study of 81 patients (n = 58 with severe TBI, n = 6 with maxillofacial trauma, n = 17 with multiple injuries), markedly greater sensitivity and specificity were demonstrated by monitoring tube placement with capnography versus auscultation alone (sensitivity: 100 vs. 94%; specificity: 100 vs. 66%, $p < 0.01$) [69]. These data confirm that capnography must always be used to monitor tube placement.

A survey reported that in Baden-Wurttemberg, only 66% of 116 emergency physician sites had capnography available in 2005 [67]. There is an urgent need for optimization. In addition, it is unknown how often capnography is actually used when available during pre-hospital endotracheal intubation, for verification of tube position, and monitoring of ventilation. The goal must be to reach a capnography rate of 100% in the prehospital and in-hospital phases of care. Based on the "Airway Management" guideline of the German Society of Anesthesiology and Intensive Care Medicine and the German DIN standards for emergency physician vehicles (NEF) [52], rescue helicopters (RTH) [50] and ambulances (RTW) [51], capnography equipment is mandatory, and the lack of appropriate equipment already constitutes organizational negligence [67].

Capnography for Normoventilation

Emergency anesthesia is used not only to maintain adequate oxygenation but also effective ventilation and thus, the elimination of carbon dioxide (CO_2), which accumulates in human metabolism. Both CO_2 accumulation (hypercapnia and hypoventilation) and hyperventilation with consecutive hypocapnia can cause damage, particularly in patients with traumatic brain injury, and must be avoided in the first 24 hours [26, 31]. This results in a vicious circle of elevated intracranial pressure, hypercapnia, hypoxemia, additional cellular swelling/edema and subsequent further increases in intracranial pressure.

In a retrospective analysis of pre-hospital care data from 100 patients intubated and ventilated in the pre-hospital setting, an $etCO_2 > 30$ mmHg was measured in 65 patients and $etCO_2 \leq 29$ mmHg in 35 patients. There was a trend towards a lower mortality in normoventilated patients (mortality rate: 29 versus 46%; OR 0.49, 95% CI: 0.1–1.1, $p = 0.10$) [33]. A prospective observational study of 74 trauma patients reported that abnormal $etCO_2$ values compared to normal etCO2 vales on hospital admission resulted in markedly increased mortality (RR 6.2; 95% CI: 1.5-26.5, p = 0.004) [82]. For patients with TBI, this study found an even higher mortality risk when normoventilation was lacking on hospital admission (RR 7.4; 95% CI: 1.0-54.5, p = 0.02) [82]. The S1 Guideline and Treatment Recommendations for Pre-hospital Emergency Anesthesia in Adults by the German Society of Anesthesiology and Intensive Care Medicine also suggests normoventilation as well as the use of capnography to monitor tube position and, indirectly, hemodynamics [19].

In a prospective observational study, only 155 of 492 patients intubated and ventilated in the pre-hospital setting showed normoventilation according to paCO2 levels of 30 to 35 mmHg on the initial arterial blood gas analysis (BGA) in the emergency department [177]. Eighty patients (16.3%) were hypocapnic (paCO2 < 30 mmHg), 188 patients (38.2%) were mildly hypercapnic (paCO2 36–45 mmHg), and 69 patients (14.0 %) were severely hypercapnic (paCO2 > 45 mmHg). The injury severity of the severely hypercapnic patients (paCO2 > 45 mmHg) was markedly increased, and these patients also had hypoxia, acidosis, or hypotension significantly more often than the other 3 groups. The mortality of trauma patients intubated/ventilated in the pre-hospital setting, both with and without TBI, was specifically lowered by normoventilation (OR: 0.57, 95% CI: 0.33–0.99). Patients with isolated TBI benefitted the most from normoventilation (OR: 0.31, 95% CI: 0.31–0.96). According to the available results, hyperventilation with consequent hypocapnia (paCO2 < 30 mmHg) appears to be particularly harmful in severely injured patients. These results make clear that beginning in the Emergency Department, ventilation must be monitored and controlled with frequent arterial blood gas analyses.

In a prospective study of 97 patients, patients monitored with capnography had significantly higher rates of normoventilation (63.2 versus 20%, $p < 0.0001$) and significantly less hypoventilation (5.3 versus 37.5%, $p < 0.0001$) compared to patients ventilated without capnography, using the 10:10 rule [77]. Thus, capnography is an orientation procedure for emergency ventilation. Nevertheless, when capnography is used as ventilation monitoring, it must be remembered that the correlation between etCO2 and paCO2 is weak ($r = 0.277$) [179]. A prospective observational study of 180 patients found that 80% of patients with etCO2 of 35–40 mmHg were actually hypoventilated (paCO2 > 40 mmHg). A prospective study of 66 intubated and ventilated trauma patients reported that patients with high ISS, hypotension, severe chest injury, and metabolic acidosis in particular showed larger differences in etCO2 and paCO2 [103]. The arterial CO2 (paCO2) therefore cannot always be directly inferred from the end-tidal CO2 (etCO2) obtained by capnography [131].

Capnography serves primarily to evaluate tube placement and to monitor on-going ventilation, with monitoring of ventilation parameters a secondary use. This was also briefly demonstrated in a retrospective cohort study of 547 trauma patients. All trauma patients, and particularly patients with severe TBI, gained from paCO2-controlled ventilation (OR: 0.33,95% CI: 0.16–0.75). There was a significant survival advantage if paCO2 was already between 30 and 39 mmHg on admission to the emergency department (OR 0.32, 95% CI: 0.14–0.75). In patients whose paCO2 was brought into the target range first in the emergency department, there was a non-significant trend towards lower mortality (OR 0.48, 95% CI: 0.21–1.09). A markedly worse survival rate was evident in trauma patients with initial paCO2 of 30–39 mmHg but were then hypoventilated (paCO2$>$ 39 mmHg), hyperventilated (paCO2 < 30 mmHg), or never attained the target paCO2 of 30–39 mmHg in the emergency department. This study also shows that paCO2 may not be freely inferred from etCO2 [178].

Using capnography to check tube placement and to detect tube displacement is advisable and indispensable. Beginning in the Emergency Department, ventilation should be regulated as soon as possible according to blood gas analyses.

Lung Protective Ventilation

A prospective randomized study reported that ventilation with small tidal volumes (6 ml/kg BW) in patients with acute respiratory distress syndrome (ARDS) led to significantly reduced mortality and lower incidence of barotrauma, and it improved oxygenation compared to ventilation with high tidal volumes [3]. The multi-center randomized, controlled trial conducted by the ARDS network confirmed these results ventilating with low tidal volumes and limiting plateau pressure to $\leq$ 30 cm H2O in patients with ARDS [128]. Chest injuries are observed in approximately 60% of polytrauma patients, with corresponding repercussions (e.g., pulmonary contusions, ARDS), and the development of mild ARDS is an independent associated factor for mortality (trauma patient mortality with mild ARDS [n = 93]: 23.7 versus without mild ARDS [n = 190]: 8.4%, $p < 0.01$) [148]. Thus, lung protective ventilation with tidal volume of 6 ml/kg BW and with lowest possible peak pressures must be implemented as soon as possible after endotracheal intubation [71].

Emergency Anesthesia

Key Recommendations:

1.14	**Recommendation**	**2016**
GoR A	**Emergency anesthesia for endotracheal intubation must be performed with rapid sequence induction due to the general non-fasting state and aspiration risk of polytrauma patients.**	
1.15	**Recommendation**	**Modified 2016**
GoR B	**Etomidate should be avoided as an induction agent because of the associated adrenal effects. Ketamine is generally a good alternative.**	

Explanation:

Emergency anesthesia is a frequently unavoidable component of proper polytrauma patient care. Anesthesia induction must be carried out in a structured way; if carried out improperly, it is associated with increased risks of morbidity and mortality [131]. In a retrospective study, compared to non-emergency intubation (n = 2136), emergency intubation (n = 241) was linked to markedly higher risks of: severe hypoxemia ($SpO2 < 70\%$: 25 vs. 4.4%, $p < 0.001$), regurgitation (25 vs. 2.4%, $p < 0.001$), aspiration (12.8 vs. 0.8%), bradycardia (21.3 vs. 1.5%, $p < 0.001$), arrhythmia (23.4 vs. 4.1%, $p < 0.001$) and cardiac arrest (10.2 vs. 0.7%, $p < 0.001$) [118].

In trauma patients, rapid sequence induction (RSI) (ileus or crash induction) is performed to secure the airway in the shortest possible time with the least aspiration risk. One prospective study evaluated the number of intubation attempts (laryngoscope through the oral cavity) necessary for successful endotracheal intubation in 1941 emergency patients over an 18-month period. The cumulative intubation success over the first three attempts in patients with intact circulatory function differed greatly among patients receiving no medications (58%, 69% and 73%), patients receiving sedation alone (44%, 63% and 75%), and patients undergoing rapid sequence induction (56%, 81% and 91%) [176]. Analysis of the Resuscitation Outcome Consortium Epistry - Trauma Registry found that endotracheal intubation without muscle relaxation was associated with a higher mortality in patients with $GCS < 9$ (OR 2.78; 95% CI: 2.03–3.80, $p < 0.01$) [46]. Other studies have also reported higher rates of failed intubation when conditions are not optimized with muscle relaxation during anesthetic induction [58, 106]. Medication-induced anesthesia like rapid sequence induction is thus crucial to the success of endotracheal intubation.

Depending on the hemodynamic state of the patient, the injury pattern, and the personal experience of the physician, various hypnotic agents can be used for induction (e.g., etomidate, ketamine, midazolam, propofol, thiopental). Each of these drugs has its own pharmacologic profile and associated side effects (e.g., etomidate: superficial anesthesia, adrenal function effects; ketamine: arterial hypertension; midazolam: slower onset of effect, superficial anesthesia; propofol: arterial hypotension; thiopental: histamine release and asthma trigger, necrosis due to extravasation). Ketamine in particular can be used, also in combination with midazolam or low-dose propofol, for rapid sequence induction in patients with marked hemodynamic instability, including patients with TBI [40, 89, 116, 131]. As analgesia, fentanyl or sufentanil are suitable for hemodynamically stable, and ketamine for unstable patients [89, 116, 131]. The recommendations listed in the current S3 guideline correspond to those in the S1 guideline and Treatment Recommendations for Pre-Hospital Emergency Anesthesia in Adults by the German Society of Anesthesiology and Intensive Care Medicine [19].

Etomidate

Etomidate will be considered here in detail, because important side effects have been recently discussed [168, 170]. A retrospective analysis of a trauma registry database found potentially negative effects from using etomidate in severe trauma [180]. Etomidate was given to 35 of 94 trauma patients (37%) during rapid sequence induction. Patients treated with and without etomidate did not differ according to demographic data (age: 36 vs. 41 years), cause of trauma, and injury severity (ISS: 26 vs. 22). After adjustment of the data (according to physiology, injury severity, and transfusion), etomidate was linked to increased risks of ARDS and multiple organ failure (adjusted OR: 3.9, 95% CI: 1.24–12.0). Trauma patients anesthetized with a single dose of etomidate also had longer hospital stays (19 versus 22 d, $p < 0.02$), more ventilation days (11 versus 14 d, $p < 0.04$) and longer intensive care stays (13 versus 16 d, $p < 0.02$).

Another retrospective study of a US trauma registry examined the results of the cosyntropin stimulation test (CST) on 137 trauma patients in intensive care units [42]. 61% of the trauma patients were non-responders. Responders and non-responders did not differ according to age (51 ± 19 vs. 50 ± 19 years), sex (male: 38 vs. 57%), or mechanism and severity of injury (ISS: 27 ± 10 vs. 31 ± 12, Revised Trauma Score: 6.5 ± 1.5 vs. 5.2 ± 1.8). In addition, there was no difference in the rates of sepsis/septic shock (20 vs. 34%, $p = 0.12$), need for mechanical ventilation (98 vs. 94%, $p = 0.38$) and mortality (10 vs. 19%, $p = 0.67$). However, responders differed significantly from non-responders regarding the incidence of hemorrhagic shock (30 vs. 54%, $p < 0,005$), need for vasopressors (52 vs. 78%, $p < 0.002$), incidence of coagulopathies (13 vs. 41%, $p < 0.001$), days in intensive care

(13 ± 12 vs. 19 ± 14, $p < 0.007$), days of mechanical ventilation (12 ± 13 vs. 17 ± 17, $p < 0.006$), and the use of etomidate as an induction hypnotic (52 vs. 71%, $p < 0.03$). The authors concluded that etomidate administration is one of the few modifiable risk factors for the development of adrenocortical insufficiency in critically ill trauma patients.

In another prospective, randomized study, trauma patients received either etomidate and succinylcholine or fentanyl, midazolam and succinylcholine for rapid sequence induction after arriving in a Level I trauma center [80]. The baseline serum cortisol concentration was recorded before anesthetic induction and an ACTH (adrenocorticotropic hormone) test carried out. Altogether, 30 patients were examined. Patients receiving etomidate (n = 18) were comparable to those receiving fentanyl/midazolam (n = 12) regarding the following patient characteristics: age (42 ± 25 vs. 44 ± 20 years, $p = 0.802$); ISS (27 ± 10 vs. 20 ± 11 years, $p = 0.105$); baseline serum cortisol concentration (31 ± 12 vs. 27 ± 10 µg/dl, $p = 0.321$). The etomidatepatients showed a smaller rise in serum cortisol concentration after the ACTH test than the fentanyl/midazolam patients (4.2 ± 4.9 µg/dl versus 11.2 ± 6.1 µg/dl, $p < 0.001$). The etomidate patients spent more days in intensive care (8 versus 3 d, $p = 0.011$), more days on mechanical ventilation (6.3 versus 1.5 d, $p = 0.007$) and more days in hospital (14 versus 6 d, $p = 0.007$). Two trauma patients died, and both had been treated with etomidate. The authors concluded that other induction hypnotics should be used rather than etomidate for trauma patients.

One prospective cohort study evaluated patients treated by physicians of an air-rescue system with either (Group 1) etomidate (0.3 mg/kg bodyweight) + succinyl choline (1.5 mg/kg bodyweight) or (Group 2) with fentanyl (3 µg/kg bodyweight) + ketamine (2 mg/kg bodyweight) + rocuronium (1 mg/kg bodyweight). A third group (Group 3) received a reduced dose ratio (1:1:1). Overall, compared to group 1, group 2 achieved better vocal cord visualization (Cormack/Lehane) and better post-procedure vital parameters. The authors reported a comparable mortality rate, each 19%, for etomidate/succinyl choline vs. fentanyl/ketamine/rocuronium [107]. This study also documents the expendability of etomidate under good intubation conditions and stable hemodynamic parameters.

Overall, analysis of the currently available data in a large survey, considering a large number of studies [1, 8, 9, 13, 34, 35, 44, 54, 59, 81, 87, 91, 97, 110, 115, 132, 137, 161], etomidate should only be used for emergency anesthesia and rapid sequence induction if no alternative medication is available or the provider has insufficient experience with these alternatives [168]. At the current time, the body of evidence is not ready for final assessment. In conclusion, the above-mentioned survey formulates its conclusion that etomidate should be limited to use in well-planned, randomized, controlled studies [168].

Endotracheal Intubation with Suspected Cervical Spine Injury

Key recommendation:

1.16	**Recommendation**	**2016**
GoR B	**For endotracheal intubation, manual in-line stabilization should be performed with temporary removal of the cervical spine immobilizer.**	

Explanation:

Normally, trauma patients, particularly polytrauma patients, are immobilized with a neck collar until cervical spine fracture can be excluded with imaging. However, a correctly positioned c-spine immobilization device restricts the mouth opening and thus, the ability to insert a laryngoscope during an intubation maneuver. The c-spine immobilizer prevents reclination of the head. Thus, a prospective multi-center study reported cervical spine immobilization as a cause of a difficult endotracheal intubation [100]. For this reason, c-spine immobilizers are replaced by manual in-line stabilization (MILS) during endotracheal intubation. In such a case, the c-spine is immobilized by an assistant using both hands to manually immobilize the c-spine. The consequent direct laryngoscopy under MILS was the standard of care in emergency situations for many years. However, MILS is not without controversy, and some negative effects have been reported [108, 145]. As an alternative to direct laryngoscopy, fiberoptic intubation by an experienced provider is the gold standard of care for conscious and spontaneously breathing, hemodynamically stable patients in-hospital [24, 131]. Current data show that video laryngoscopy allows good laryngeal visualization when the c-spine immobilizer is in place, so that it can be used here as an alternative procedure [29, 83, 84, 160].

Video Laryngoscopy

Key Recommendations:

1.17	**Recommendation**	**New 2016**
GoR B	**Video laryngoscopy should be liberally considered pre-hospital and in-hospital given the better adjustability of vocal cord level and optimal chance of primary intubation success.**	
1.18	**Recommendation**	**New 2016**
GPP	**Video laryngoscopy must be on hand pre-hospital and in-hospital and used as primary and reserve procedure.**	

Explanation:

There is increasing evidence for the use of video laryngoscopy during in-hospital airway management. Several recently-published studies have shown that first pass intubation success (FPS) can be significantly improved with the primary and increasing use of video laryngoscopy (VL) [28]. During endotracheal intubation of 619 patients in an emergency department, the FPS with VL was twice as high as with conventional direct laryngoscopy (DL) (85.0 vs. 81.5 %; 95% CI: 1.1-3.6) [171]. Multivariate regression analysis showed an advantage for FPS using VL vs. DL (OR 1.96; 95% CI: 1.10–3.49, p = 0.23). With very experienced providers, VL-assisted intubation increased FPS more than 2.5-fold compared to DL (OR 2.7; 95% CI: 1.03–7.09, p = 0.043). Another study of 3rd year emergency medicine residents in the U.S. found that EPS improved to 90% using VL vs. 73% for DL [144]. Similar results were found in a cohort study with 313 patients each in VL and DL groups, with comparable intubation conditions in the operating room area (94 vs. 81 %) [86]. A randomized, controlled trial (RCT) of in-hospital anesthesia induction reported increased FPS with VL vs. DL (93 vs. 84%, p = 0.026), with concomitant better cord visualization (Cormack/Lehane, C/L I/II: 93 vs. 81%, $p < 0.01$) [11]. Intubation success depends on cord visualization. With VL, positive effects are seen because there is better visualization. Although intubation time is somewhat longer in VL vs. DL (46 vs. 33 seconds, $p < 0.001$), the complication rate of the two procedures was comparable (20 vs. 13%, p = 0.146) [11]. In another prospective monocenter observational study on intubation in trauma patients in the Emergency Department found marked improvement of FPS (76 vs. 71%, p = 0.17, OR 0.55; 95% CI: 0.35-0.87, p = 0.01) and overall success rate (88 vs. 83 %, p = 0.05) in VL vs. DL. In this study, the injury severity was higher in the VL group (ISS: 2.4 vs. 20.5, p = 0.01) [111]. A randomized controlled trial of 623 patients in the Emergency Department with indications to intubate according to the EAST trauma guideline (airway obstruction, hypoventilation, severe hypoxemia, GCS < 9, and hemorrhagic shock, supplemented with altered level of consciousness, uncooperativeness, severe pain), which induced anesthesia of stable patients with thiopental (4 mg/kg bodyweight) and succinyl choline (1.5 mg/kg bodyweight) and of hemodynamically unstable patients with reduced doses of thiopental or etomidate (0.2-0.4 mg/kg bodyweight), found a minimal, non-relevant longer intubation time for VL vs. DL (71 vs. 56.5 seconds, p = 0.002). In this study, FPS (80 vs. 81%, p = 0.46) and mortality (9.2 vs. 7.5%, p = 0.43) were comparable for VL and DL [185]. In a prospective observational study in an Emergency Department with 2677 patients (of these, 1173 trauma patients), VL significantly reduced the frequency of short-term esophageal intubation vs. DL (1.0 vs. 5.1%, $p < 0.001$) [142]. There were significantly more complications after short-term, recognized esophageal intubation compared to patients intubated correctly from the beginning (aspiration: 8.6 vs. 1.4%, arrhythmia: 3.2 vs. 0.5%, hypotension: 2.2 vs. 0.7%, hypoxemia: 35.5 vs. 16.8%). Another study by Sakles et al. [143] found that for 255 patients intubated with VL versus 495 with DL, there were marked advantages for VL regarding FPS (OR 2.2; 95% CI: 1.2–3.8) and the overall success rate (OR 12.7; 95% CI: 4.1–38.8). A prospective observational study in an intensive care unit with 290 patients found for VL versus DL higher FPS (78.6 vs. 60.7%, p = 0.009), higher overall success rate of endotracheal intubation (98.3 vs. 91.2 %, p = 0.04), and higher success rate in patients with a difficult airway (76.3 vs. 57.7 %, p = 0.04) [121]. In this study, VL also showed better cord visualization (CL1: 85.8 vs. 61.8%, $p < 0.001$). A randomized controlled study (RCT) in an intensive care unit found higher FPS for VL (75 vs. 40%, $p < 0.01$) and a decreased rate of > 2 intubation attempts (9 vs. 27%, p = 0.02) as well as decreased time for the intubation procedure (120 vs. 218 seconds, $p < 0.01$) compared to DL. VL resulted in better visualization of the vocal cords compared to DL (CL1: 93 vs. 57%, $p < 0.001$) [150]. Additional pre-hospital studies of trauma patients appear to support these observations [84].

Currently, the high price of a video laryngoscope is often cited as an argument against use in the pre-hospital setting. However, the first studies in the pre-hospital setting have given overwhelming evidence in favor of video laryngoscopy. In a prospective monocenter observational study in an air rescue system with a high trauma fraction of 71.5%, VL was successful in 227 of 228 patients (99.6%), and supraglottic airway was necessary in only one case (0.4%) [83]. In 57 of these patients, who were treated by experienced anesthesiologists, vocal cord visualization was improved from CL grade III/IV with DL to grade I/II with VL ($p < 0.001$). Similar positive results were achieved during intubations by U.S. paramedics using VL in a retrospective data analysis of an air rescue system over a nine-year period with 790 emergency patients with a trauma fraction of 60%. Here, VL showed a higher FPS than DL (94.9 vs. 75.4%, $p < 0.0001$) [23]. VL increased the success rate of endotracheal intubation within two attempts (97.4 vs. 89.2%, p = 0.0002). The overall intubation success rate using VL was also significantly higher than with DL (99.0 vs. 94.9%, $p < 0.011$). In addition, VL reduced the average number of intubation attempts until success (1.08 vs. 1.33, $p < 0.0001$) and the need to use supraglottic airways by group (0.5 vs. 3.2%, p = 0.036) [23].

The advantage of VL is particularly evident with c-spine immobilization. In the above-mentioned prospective, monocenter observational study by Michailidou et al. [111], the subgroup of patients with c-spine immobilization had significantly higher FPS with VL than DL (87 vs 80%, p = 0.03) [111]. In this study as well, there were fewer complications for VL-assisted intubations.

Limitations of the procedure are present in 14% of cases because of the following: strong light causing reduced contrast or contamination of the objective lense with blood or secretions [21, 83, 84]. In this context, a VL blade should be used, which allows DL in addition to indirect VL (e.g., Macintosh blade). If the airway is particularly difficult, a specially curved laryngoscopy blade can be carried, which allows only indirect laryngoscopy (e.g., D-blade).

The evidence table for this chapter is found on page 48 of the guideline report.

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1.3 Volume Replacement

Key Recommendations:

1.19	**Recommendation**	**2016**
GoR B	**Volume replacement should be begun in severely injured patients. In cases of uncontrollable bleeding this should be done at a reduced level to maintain minimal hemodynamic stability while not increasing blood loss.**	
1.20	**Recommendation**	**2016**
GoR B	**In hypotensive patients with traumatic brain injury, volume replacement should be performed with the goal of maintaining normal blood pressure.**	
1.21	**Recommendation**	**Modified 2016**
GoR A	**Intravenous access must be placed in trauma patients.**	
1.22	**Recommendation**	**Modified 2016**
GoR 0	**Volume replacement can be foregone when there is no evidence of volume depletion.**	

Explanation:

The hypoperfusion produced by traumatic hemorrhage and consequent hemorrhagic shock results in an imbalance between oxygen supply and tissue demand [45, 72]. This disturbance in the microcirculation is blamed for secondary damage that occurs after hemorrhagic shock. Thus, the goal of volume replacement should be improvement of the microcirculation and with it, organ perfusion. In the past, expert opinion was that aggressive volume replacement has favorable effects on the outcomes for acutely bleeding patients [2, 46]. However, four current randomized controlled trials have not confirmed this rationale for volume replacement during the pre-hospital phase [12, 31, 51, 72]. A study from Turner et al. [72] randomized patients to receive or not receive volume replacement. 1309 patients were included. The results of both groups did not differ regarding mortality, morbidity, and long-term outcome [72].

In 2002, Dutton et al. [31] assigned 110 patients in hemorrhagic shock to two different volume replacement regimens. For one group, the target systolic blood pressure (SBP) was over 100 mmHg, and for the other, 70 mmHg. No differences were evident. Four patients of each group died. Morisson et al. [51] used a very similar protocol. Here too, patients with hemorrhagic shock were assigned to treatment groups with different target blood pressures. In this case, the mean arterial blood pressure (MAP) was used. The target MAP for group 1 ($n = 44$) was 50 mmHg, and for group 2 ($n = 46$) was 65 mmHg. Group 1 patients had significantly decreased mortality in the first 24 hours (1 vs. 8 patients).

Another study from Bickell et al. [12] found a negative survival effect from volume replacement after bleeding. However, only patients with penetrating chest injuries were included. There were 1069 patients in the study. In this select population, volume replacement given in the pre-hospital phase increased mortality from 30 to 38% and increased post-operative complications from 23 to 30%. The authors concluded that pre-hospital volume replacement should not be administered and that surgical treatment should be initiated as rapidly as possible.

A meta-analysis by Wang et al., referring essentially to these four studies, concluded that forced volume replacement leads to increased mortality [77]. On the other hand, the heterogeneity of the patient population was pointed out.

Another large meta-analysis from Curry et al. assessed the literature for the extent today's volume replacement therapies have been found to improve mortality, coagulation, and need for transfusion and concluded that there are no significant improvements [27].

In addition to the four controlled studies mentioned, there are a number of publications that join in the conclusions [11, 42, 58, 67, 71]. However, the authors continually emphasize the situation of uncontrolled intrathoracic or intraabdominal bleeding. In such cases, surgical treatment should begin as soon as possible and not be delayed by pre-hospital measures. Moderate volume replacement with "controlled hypotension" and systolic blood pressure of 90 mmHg should be the goal [31, 45, 60]. In patients with cardiac injury or TBI, this is also seen as critical [30, 45, 69]. On the other hand, other authors promote forced volume replacement, and often for different patient cohorts e.g. with extremity injuries without uncontrolled bleeding [46, 52, 62]. Other studies have not confirmed the results of Bickell [39, 81].

A retrospective study by Balogh et al. [10] compared 156 patients in shock treated with supra-normal volume replacement (resuscitation) with others receiving less aggressive treatment that stopped at the oxygen delivery index (DO2I). An oxygen delivery index (DO2I) >/= 500 ml/min per square meter body surface area (BSA) was set for group 1, and DO2I >/= 600 ml/min/m2BSA for group 2. Increased intrabdominal pressure, associated with increased organ failure, was observed in group 2.

Once the hospital is reached and surgery begun, or in controlled bleeding situations, most studies recommend initiating intensive volume replacement. Expert opinion recommends a target hematocrit value of 25-30% as a reference for the quantity of volume replacement [13, 34]. There are no controlled studies on this topic.

Catecholamine administration is disputed and is considered only as a last resort [1, 35].

In one study, the pre-hospital treatment time was extended by 12-13 minutes because of volume replacement interventions [72]. Some authors interpret this time loss as less relevant [72], and others as a major detrimental factor on mortality [63, 64]. However, it is unclear whether this statement from North America is transferrable to the German emergency physician system.

Since venous access is a fundamental prerequisite for the administration of any medication or volume replacement, each patient must have venous access placed.

Table 6: Pre-Hospital Volume Replacement–Mortality

Study	LoE	Patient Collective	Mortality with Volume Replacement	Mortality without Volume Replacement
Turner et al. 2000 [72]	1b	Multiply injured patients (n = 1309)	10.4%	9.8%
Bickell et al. 1994 [12]	2a	Patients with penetrating chest trauma (n = 1069)	38%	30%

Crystalloid versus Colloid

Key Recommendations:

1.23	**Recommendation**	**2016**
GoR B	**Crystalloids should be used for volume replacement in trauma patients.**	
1.24	**Recommendation**	**Modified 2016**
GoR A	**Isotonic saline solution must not be administered.**	
1.25	**Recommendation**	**Modified 2016**
GoR B	**Balanced crystalloid, isotonic electrolyte solutions should be used.**	
1.26	**Recommendation**	**Modified 2016**
GoR 0	**Balanced solutions, i.e. Ringer's acetate or malate instead of lactate can be considered.**	
1.27	**Recommendation**	**2016**
GoR A	**Human albumin must not be used during pre-hospital volume replacement.**	

Explanation:

The choice of infusion solution has been debated for years. Since most of the data came from animal studies or operations, the evidential value was always limited. The use of colloids in particular was the subject of intense debate. In 2013, however, the German Federal Institute for Drugs and Medical Devices (*Bundesinstituts für Arzneimittel und Medizinprodukte*) circulated urgent safety information markedly restricting the use of solutions with hydroxyethyl starch (HES) [50]. Thus, HES is no longer important for volume replacement.

Even prior to the warning by the Federal Institute, there were indications that the use of crystalloids is advantageous for trauma patients. In 1989, Velanovich et al. found a 12.3% decrease in mortality when crystalloid solutions were used for volume replacement [74]. In 1999 Choi et al. confirmed this result and hypothesized that mortality is decreased for trauma patients treated with crystalloid [20]. A Cochrane analysis performed in 2008 yielded no difference between colloid and crystalloid treatment after trauma [16-18]. From this, the authors concluded already that colloid could be foregone as volume replacement, since no advantage was evident and crystalloids are less costly.

Regarding the choice of crystalloid, Ringer's Lactate is preferable to isotonic saline [25, 36, 38, 68]. Experimental studies have reported dilution acidosis occurring after infusion of large quantities of isotonic saline [53, 54]. Lactate metabolism results in bicarbonate and water. Thus, the addition of lactate to a Ringer's balanced electrolyte solution prevents dilution acidosis and buffers the bicarbonate pool. More recent studies have reported experimental disadvantages of Ringer's Lactate. According to these reports, Ringer's Lactate triggers neutrophil granulocyte activation, thus increasing lung damage [5-7, 57]. It also appears to result in increased rates of granulocyte apoptosis [28]. This has not been confirmed in clinical studies.

Lactate levels in the plasma are used as a diagnostic shock parameter. Because Ringer's Lactate results in iatrogenic increase in plasma lactate levels, it can interfere with diagnosis [55, 56]. Ringer's Malate or Ringer's Acetate can be used as replacement solutions. Animal studies have found decreased mortality when Ringer's Malate is used. The challenge of the slight hypoosmolarity of Ringer's Lactate and the associated potential for increased cerebral edema after traumatic brain injury is not present with Ringer's Acetate/Malate solutions, since these are completely isoosmolar [55, 82]. In summary, the use of Ringer's Lactate is no longer worthy of recommendation.

Because of the clear limitations for HES in volume replacement, other colloids like gelatin or albumin have experienced a renaissance. However, the use of albumin appears to be associated with increased mortality after severe trauma, and because of additional logistical reasons like the need for cooling and glass bottles, it is not recommended [32, 36]. Regarding the use of gelatin, there is the risk of an immune reaction. In 1977, Ring et al. published a study in Lancet that this risk is significantly higher than for other colloids (probability of an immune reaction: HAES 0.006%, dextran 0.0008%, gelatin 0.038%) [59]. Because of fibrin polymerization disorders, a coagulation disorder can occur, although in comparison to HES or dextran, this role for gelatin is less important [65]. "Infusions containing HES should be used to treat patients with hypovolemia from acute blood loss only when the administration of crystalloid alone is considered insufficient" [50]. The authors of the chapter point out, however, that patients with suspected trauma-induced coagulopathy should stay away from artificial colloids as volume replacement.

Hypertonic Solutions

Key Recommendations:

1.28	**Recommendation**	**2016**
GoR 0	**Hypertonic solutions can be used for hypotensive patients with multiple injuries after blunt trauma.**	
1.29	**Recommendation**	**Modified 2016**
GoR 0	**In cases of penetrating trauma, hypertonic solutions can be used provided pre-hospital volume therapy is being performed.**	
1.30	**Recommendation**	**2016**
GoR 0	**Hypertonic solutions can be used in hypotensive patients with severe traumatic brain injury.**	

Explanation:

In recent years, the use of hypertonic 7.5% saline solutions has gained increasing importance, especially in the realm of pre-hospital volume replacement. As described above, disordered microcirculation appears to be the damaging factor in cases of traumatic hemorrhagic shock.

Hypertonic solutions work by mobilizing intracellular and interstitial fluid into the intravascular space, and thus, improving microcirculation and the overall blood rheology.

Although most studies have infused pure 7.5% saline solution at 4 ml/kg bodyweight, in Germany, only the combination solutions with HES (Hyperhaes®) or 6% dextran 70 (RescueFlow®) have been used. Because of the problems discussed above regarding the use of HES, soon neither of these solutions will be available in Germany. Thus, the Southwest German Emergency Physicians' Working Group (*Arbeitsgemeinschaft Südwestdeutsche Notärzte e.V.*) has recommended either importing RescueFlow® (250 ml 7.5% NaCl solutions with 6% dextran 70) or using 10% NaCl solution. Neither recommendation is unproblematic. In Germany, the import and use of non-distributed pharmaceuticals requires individual prescription with corresponding documentation, and the allergic potential of dextran remains [59]. In addition, the dosage of hypertonic solutions has been extensively studied by Rocha e Silva et al., and is explicitly given as 7.5% saline. All other dosages have increased mortality in dogs [61]. The damaging factor is the potential hypernatremia. The use of a 10% saline solution increases the quantity of NaCl from 18g to 20g. Thus, use must be considered critically and should be first evaluated in studies.

Although there is much promising evidence for hypertonic infusions in the literature, the poor availability of appropriate hypertonic solutions allows no higher grade of recommendation.

Disordered microcirculation is the essential factor leading to complications from hemorrhage. Hypertonic saline solutions work by rapidly mobilizing intracellular and interstitial fluid into the intravascular space and thus, improving blood rheology and with it, the microcirculation [43]. Controlled studies have shown significant advantages for hypertonic infusions. In 2004, Bunn et al. used a Cochrane review to evaluate hypertonic versus isotonic solutions [17]. The authors concluded that the available data was not sufficient to make a final judgment regarding use of hypertonic solutions. In 1991, in two controlled randomized studies, Mattox et al. and Vassar et al. found survival advantages for the use of hypertonic solutions, particularly after traumatic brain injury [49, 73]. The work of Alpar et al. from 2004 took the same direction in a study of 180 patients. There were improved outcomes, particularly in patients with TBI [3]. In 2009, Baker et al. also reported a positive effect for hypertonic solutions given after TBI [9]. Another controlled study of 229 patients from 2004, however, found no significant difference in long-term outcomes after TBI [24]. Positive effects for the clinical treatment of TBI have been reported in other studies. Wade et al. and Vassar et al. reported improved mortality after TBI after initial therapy with hypertonic solutions [73, 76]. Mortality decreased from 60 to 49% in the Vassar et al. study, and from 37.0 to 26.9% in the Wade et al. study with use of hypertonic solution. In the follow-up treatment for increased intracranial pressure, the combination of hypertonic solution/HES in particular showed lowering effects [37, 41, 66, 78-80]. However, this effect was not confirmed in a controlled clinical trial [67]. In another current study by Bulger et al., no benefit from hypertonic solutions was evident, so that the study was discontinued after 1313 patients [67]. Wade et al. performed a comparative investigation through a short meta-analysis of 14 studies of hypertonic saline solutions with and without dextran, and found no relevant benefit for hypertonic solutions [76]. In 2003, the same author reported a positive effect of hypertonic solutions for penetrating trauma. In a double-blind study, 230 patients received initial infusion of either hypertonic NaCl solution or an isotonic solution. Mortality of patients receiving hypertonic NaCl solution was 75.5%, significantly less than patients receiving isotonic solution, with 82.5%. The rates of surgery and bleeding were the same. The authors concluded that hypertonic solutions improve survival after penetrating trauma without increasing bleeding [75].

A current study of 209 polytrauma patients with blunt trauma by Bulger et al. [15] compared Ringer's Lactate to hypertonic NaCl solution with dextran. The endpoint of the study was ARDS-free survival. The study was discontinued after intention-to-treat analysis, because there was no apparent difference. In one subgroup analysis, an advantage for hypertonic solution with dextran was evident only after massive transfusion. Even the most recent publication by this group reported no advantage for hypertonic solutions after hemorrhagic shock [15]. In fact, patients not requiring transfusion had even higher mortality rates after administration of hypertonic solution (28-day mortality hypertonic solution with dextran: 10%, isotonic solution: 4.8%, p<0.01) [15].

Immunological effects from hypertonic solutions have also discussed. Experimental reports have described a reduction in neutrophil activation and the pro-inflammatory cascade [5-8, 22, 23, 26, 29, 57, 70]. Junger et al. also attempted to demonstrate an inhibitory effect of pure hypertonic solutions on post-traumatic inflammation in trauma patients [40].

Hypertonic solutions lead to a rapid increase in blood pressure and reduced volume needs [4, 14, 19, 21, 33, 44, 47, 48, 80]. The extent to which this affects treatment outcomes cannot yet be conclusively answered by the literature.

The evidence table for this chapter is found on page 80 of the guideline report.

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1.4 Thorax

Diagnosis

The decision of whether to perform drainage/decompression of the pleural space is based on the examination, the assessment of the findings (diagnosis), and the risk-benefit analysis of the intervention (the certainty of diagnosis with limited diagnostic capabilities, time factor, concomitant problems as well as the risks of the intervention itself).

Examination

Key Recommendations:

1.31	**Recommendation**	**2011**
GoR A	**Clinical examination of the chest and respiratory function must be performed.**	
1.32	**Recommendation**	**2011**
GoR B	**The examination should include at least respiratory rate measurement and lung auscultation. Repeated examinations should follow.**	
1.33	**Recommendation**	**Modified 2016**
GoR 0	**Inspection, palpation, and percussion of the chest as well as pulse oximetry and monitoring of ventilatory pressure and capnography in ventilated patients are also useful.**	

Explanation:

Initial Examination

The physical examination of the patient is necessary to establish a diagnosis, which is necessary to initiate treatment interventions. Acutely life-threatening problems can only be recognized by examination. Thus, even without scientific confirmation, it is absolutely required [88].

Scientific research studies focus generally only on auscultation, determination of respiratory rate as well as assessment for spontaneous and elicited pain/tenderness. Therefore, only experience can define the scope of physical examination necessary in a pre-hospital emergency setting. In an emergency situation at the scene of trauma, once the vital parameters have been examined and stabilized, the initial examination should include measurement of the respiratory rate and auscultation (presence and quality of breath sounds bilaterally) [15, 35, 39, 40]. All of these signs are correlated with significant pathologies or directly influence medical decisions. Other signs of thoracic injuries can be identified using other examination techniques of inspection, palpation, percussion, and technical monitoring [53] (Table 7). Capnometry can indicate a problem with ventilation, although this is non-specific for particular injuries or disorders.

Table 7: Special Focus of the Physical Examination to Identify Relevant Thoracic Injuries

Examination	Special focus on:
Inspection	**Respiratory rate**
	Symmetrical excursion on respiration
	Unilateral bulging
	Paradoxical respiration
	Dyspnea
Palpation	**Elicited and spontaneous tenderness/pain**
	Pain points
	Crepitus
	Subcutaneous emphysema
	Instability of the bony thorax
Percussion	Hyperresonance
Auscultation	**Presence and quality of breath sounds bilaterally**
Technical monitoring	Pulse oximetry
	Ventilation pressure
	Capnography
	(Ultrasound)
	(Lung scan)

All of the examination techniques mentioned above are used to detect life-threatening or potentially life-threatening disorders and injuries that can make immediate and specific interventions or logistic decisions necessary right away. All of the diagnostic measures performed pre-hospital are without specific risks. The disadvantage is loss of time, which is generally minimal.

Some findings are strongly dependent on the examiner, the patient, and the environment. Surrounding noise levels can make auscultation difficult or impossible. Such circumstances need to be considered when selecting and interpreting the primary diagnostic studies [35, 39, 72, 134].

Monitoring

Respiratory rate and auscultation as well as pulse oximetry and ventilation pressure monitoring/capnography when necessary should be continued, since airway problems, tube displacement, tension pneumothorax, or acute respiratory insufficiency can develop dynamically. Serial examinations can serve as control of the interventions that have already been performed.

Diagnosing Pneumothorax

Key Recommendations:

1.34	**Recommendation**	**2011**
GoR A	**A provisional diagnosis of pneumothorax and/or hemothorax must be made in cases of unilateral absence or decrease in breath sounds (after controlling for correct tube placement). The lack of such findings on auscultation, particularly with normal respiratory rate and absence of thoracic discomfort, generally rules out a large pneumothorax.**	
1.35	**Recommendation**	**2011**
GoR B	**Potential progression of a small, initially (in the pre-hospital stage) undetectable pneumothorax should be kept in mind.**	

Explanation:

At the present time, there are no evaluated methods available in the pre-hospital setting to definitively detect or exclude pneumothorax.

Ultrasound Examination

In hospital conditions, an ultrasound examination shows evidence of pneumothorax and hemothorax (lung sliding, seashore sign, B-lines/comet tail artifacts, etc.) with extreme accuracy [5, 57], and is superior to both clinical diagnosis and standard radiography. However, the estimated magnitude of a confirmed pneumothorax is uncertain and so far, poorly documented. Similarly, there has been little study of the risk-benefit analysis including the therapeutic consequences from the results of the investigation. In addition to dependence on the examiner, the loss of time and misdiagnosis by less experienced examiners must be considered. In particular, there has been no reliable experience with pre-hospital use, so a general recommendation can't be given. Nevertheless, pre-hospital ultrasound performed by an experienced examiner can contribute to confirmation of a provisional diagnosis of pneumothorax. Increasing experience with ultrasound diagnosis of pneumothorax in the pre-hospital setting could lead to more prominence in the coming years. For these reasons, the lack of expert consensus means that no recommendation for or against the use of pre-hospital ultrasound for the diagnosis of pneumothorax can be made. A new radar-based technology with a hand-held device has shown initial promising results for the detection of pneumothorax [4, 90]. Further studies must be performed to confirm the value and practicality of widespread use before recommendations can be given.

Auscultation, Dyspnea, Pain

A systematic review [137] analyzed studies regarding the accuracy of clinical examination for the diagnosis of pneumothorax.

Sensitivity was 90%. The specificity of a unilateral decrease or lack of breath sounds, i.e. the probability that patients without pneumothorax would not have these findings, is very high, with 98%. The positive predictive value, i.e. the probability that pneumothorax is actually present when breath sounds are decreased, is also very high with 86 - 97%. Pneumothorax not recognized on auscultation had an average volume of 378 ml (max 800 ml), and hemothorax of 277 ml (max 600 ml). In this study, thus, no large, acutely life-threatening lesions were missed.

A requirement for this is that the appropriate position of the endotracheal tube (when present) must be ensured, as much as possible (capnography). The studies mentioned here were performed in the emergency department of the hospital, and not at the scene of the trauma. They appear to be transferable, however, since there are also many comparable disruptions (e.g. increased noise, surrounding activity) in the emergency department. False positive findings occur occasionally (4.5% of cases in [87]) with tube misplacement, diaphragmatic rupture [1, 6], or ventilatory disruption (large atelectasis, movement on deep respiration).

In cases of severe bilateral chest trauma, bilateral pneumothorax needs to be considered. In such cases, atypical findings might be present.

Data regarding differentiation between pneumothorax and hemothorax or a mixed clinical picture are not available. Here percussion can be helpful, although this has only limited relevance in the pre-hospital setting, since differentiation between pneumothorax and hemothorax has no verifiable effect on the need for therapy (see below). Ultrasound examination can make the distinction (discussed above).

Although the symptoms of dyspnea and tachypnea are difficult to quantify when patients have decreased levels of consciousness, normopnea (respiratory rate between 10 - 20 breaths per minute) can be used in clinical practice as an indication. Multiple studies have found that normopnea after blunt trauma is a very good sign that large hemo/pneumothorax can be excluded (specificity 98%). On the other hand, the presence of dyspnea does not indicate that pneumothorax is present (sensitivity 43%).

Patients with normal levels of consciousness can be asked directly about pain. In addition, there is the physical examination for tenderness on palpation in the chest area. Only one study has reported on the importance of a lack of pain/tenderness, which shows good specificity particularly for acute trauma [23]. Thoracic pain can only be used for accurate diagnosis in combination with other findings and the overall clinical picture.

Table 8 gives a summary of the accuracy of the three criteria, individually and in various finding constellations. Highest accuracy is when all three criteria are present, followed by pathological auscultation in combination with one of the other two criteria. Conversely, unremarkable auscultation, palpation, and normopnea virtually exclude the presence of hemo/pneumothorax [23].

Table 8: Statistical Probability for Clinically Relevant Hemo/Pneumothorax with Various Combinations of Findings After Blunt Chest Trauma (Basic Assumption: 10% Prevalence as Pre-Test Probability and Test Independence). Modified according to [137]:

Thoracic Pain (Sensitivity 57 %, Specificity 79 %)	Dyspnea (Sensitivity 43 %, Specificity 98 %)	Auscultation (Sensitivity 90 %, Specificity 98 %)	Probability of Hemo/ Pneumothorax
+	+	+	> 99 %
+	+	-	40 %
+	-	+	89 %
+	-	-	2 %
-	+	+	98 %
-	+	-	12 %
-	-	+	61 %
-	-	-	< 1 %

Other Investigations and Pneumothorax

Detection of subcutaneous emphysema is considered a sign of pneumothorax. However, there are no good diagnostic studies on this topic available. The specificity and the positive predictive value are not known. Sensitivity is low, between 12 and 25 % [45, 125]. However, a higher positive predictive value is suspected due to non-systematic experience.

A 30-year-old study reported a 100% sensitivity of subcutaneous emphysema for tension pneumothorax in intensive care patients. This data is possibly not transferable to acute trauma patients in the pre-hospital phase [130].

Considering the relatively high rate of false findings, the presence of flail chest and crepitus should be assessed as indications of chest trauma, but not of pneumothorax.

Pneumothorax and Progression

The potential progression of an initially asymptomatic pneumothorax is important, particularly in air rescue. The progression of pneumothorax can vary considerably among individual patients. The full spectrum from in-hospital discovery to rapid progression is possible. Certain clues can be drawn from observations of small pneumothoraxes. A small retrospective series was performed of 13 patients with occult pneumothorax treated with observation. Of these, six were mechanically ventilated. In two cases, chest tube drainage was necessary for progressive pneumothorax on the 2nd and 3rd days after admission [38]. In a prospective randomized study of 21 patients with occult pneumothorax treated expectantly, 8 cases progressed and three of these were tension pneumothorax. All of these patients were mechanically ventilated [59]. The three tension pneumothoraxes occurred in the operating room, postoperatively in the intensive care unit, and during a prolonged stabilization phase, but more specific data regarding the hours after trauma are not available. A period of at least 30 - 60 minutes after hospital admission are assumed. In another prospective randomized study on therapy for occult pneumothorax, pneumothorax progression requiring intervention showed a higher tendency in patients treated conservatively (9.5%) versus patients treated with chest tubes (5.6%) [24, 139]. Information regarding the timeframe of pneumothorax progression was not available. A prospective multicenter study reported a 6 % progression rate of occult pneumothorax requiring chest tube drainage, and 14 % in ventilated patients. In a randomized study in ventilated patients (for an operation) with occult pneumothorax, all reported parameters were comparable except whether a chest tube had been placed or not [83]. 20% of patients treated with initial observation required chest tube placement over the course of care, although less than half of these because of pneumothorax progression, i.e. in 8% of the total patient population. A review by Yadav et al. [139] observed only three of the older, smaller studies, and contributed no additional evidence.

As far as the standard radiographic data of occult pneumothorax is transferable to non-clinically diagnosable pneumothorax, the risk of progression is rather low (between 6 and 9.5 %, i.e. in fewer than every tenth patient). For ventilated patients, this rate is higher (approximately

14 %), so that the classic situation of progressive pneumothorax (up to tension pneumothorax) after intubation actually occurs in one of seven patients receiving positive pressure ventilation [106].

In summary, the data suggests that small, clinically non-diagnosable pneumothorax, especially in non-ventilated patients, progresses relatively seldom (and most only slowly) as a rule, and thus, generally does not require emergency decompression in the pre-hospital setting. Nevertheless, progression of even an initially clinically undetectable pneumothorax must be reckoned with. Increased attention to monitoring, progress checks, and readiness for decompression are necessary to recognize cases of progression in a timely manner.

Diagnosis Tension Pneumothorax

Key Recommendations:

1.36	**Recommendation**	**Modified 2016**
GoR B	**A provisional diagnosis of tension pneumothorax should be made in cases of unilaterally absent breath sounds on lung auscultation (after controlling for correct tube placement) along with the presence of typical symptoms, particularly severe respiratory or hemodynamic instability.**	

Explanation:

A number of systematic reviews have been published regarding the diagnostic accuracy of examination findings in the case of tension pneumothorax, based on cohort studies, small case series, and case reports. However, there is no uniform understanding of exactly what falls under the definition of tension pneumothorax. Definitions range from pneumothorax with life-threatening consequences to vital functions, to a hiss of escaping air on needle decompression, to mediastinal shift on chest x-ray, to increased ipsilateral intrapleural pressure, and on to hemodynamic compromise [89].

Experimental investigations have found that the respiratory changes and paralysis of the respiratory center as a result of the hypoxia precede circulatory arrest. The hypotension, which culminates in circulatory arrest, is a late sign of tension pneumothorax [14, 122].

A review article from 2005 characterized "shortness of breath," and "tachycardia" as the typical and most common symptom/sign of tension pneumothorax in conscious patients [89]. The same authors also found, however, that the hemodynamic symptoms occur earlier in ventilated patients, and that respiratory symptoms and the drop in blood pressure often manifest at the same time. In mechanically ventilated patients, extremely elevated or increasing airway pressures are another important sign found in some 20% of patients with hemo/pneumothorax [15, 39]. A current systematic review reported significant differences in the manifestation of tension pneumothorax between spontaneously breathing patients and those being mechanically ventilated [120].

Chest pain, tachypnea, and decreased breath sounds occurred in more than 45 % of spontaneously breathing patients. Dyspnea/respiratory distress, hypoxia with oxygen demand, tachycardia, and hyperresonance were present in 30 to 45 % of cases. Tracheal deviation (15-30 %) or hypotension (when present, with a slow progression), distended neck veins, subcutaneous emphysema, cardiac arrest (each under 15%) were much more seldom.

In contrast, in ventilated patients, the most common signs (> 45%) were decreased breath sounds as well as hypotension (often with an acute beginning) and hypoxia. Also common (30-45 %) were tachycardia, subcutaneous emphysema, and cardiac arrest.

The diagnostic accuracy of the individual clinical signs and findings has not yet been evaluated.

According to expert opinion, the combination of (unilateral) absence of breath sounds (with verified tube position) and changes of vital respiratory or hemodynamic parameters makes tension pneumothorax so probable that the diagnosis should be given and the necessary therapeutic interventions should be performed. Further diagnostic studies represent avoidable delay and should be foregone. The consequences of a false positive tension pneumothorax diagnosis are much less severe than those from the omission of required decompression.

Indications for Pleural Decompression

Key Recommendations:

1.37	**Recommendation**	**New 2016**
GoR A	**Tension pneumothorax is the most frequent reversible cause of traumatic cardiac arrest and must be decompressed in the pre-hospital setting.**	
1.38	**Recommendation**	**2011**
GoR A	**Clinically suspected tension pneumothorax must be decompressed immediately.**	
1.39	**Recommendation**	**2011**
GoR B	**Pneumothorax diagnosed on auscultation should be decompressed in patients receiving positive pressure ventilation.**	
1.40	**Recommendation**	**2011**
GoR B	**Pneumothorax diagnosed on auscultation should be treated expectantly with close observation in non-mechanically ventilated patients.**	

Explanation:

There are no investigations comparing intervention and expectant therapy. The treatment recommendations are based on expert opinions and consideration of probabilities.

Tension pneumothorax

Tension pneumothorax is an acute life-threatening situation. Left untreated, it generally leads to death. Death can occur within minutes of the onset of signs of insufficient respiratory and hemodynamic function. There is no alternative to decompression. Expert opinion is that particularly in cases of circulatory or respiratory impairment, emergency decompression must be performed immediately and that the time lost in transport even to a hospital in the immediate vicinity represents an unjustifiable delay. A study of 3500 autopsies identified 39 cases of tension pneumothorax (incidence 1.1%), of which half were not diagnosed while the patient was still living. Among soldiers of the Vietnam war, tension pneumothorax occurred in 3.9 % of all patients with chest injuries and in 33 % of soldiers with deadly chest injuries [99]. An analysis of 20 patients categorized as unexpected survivors according to TRISS prognosis reported that seven of them underwent pre-hospital decompression for tension pneumothorax [27]. In cases of pre-hospital resuscitation post-trauma, spontaneous circulation was restored in 4 of 18 patients with decompression (once with needle, four with mini-thoracotomy) [105]. An analysis of patients with trauma-associated circulatory arrest identified decompression of tension pneumothorax as the most important factor contributing to improved prognosis [76]. In a current analysis, untreated tension pneumothorax was identified as one of the most frequent preventable causes of death [84]. Through a special training program for paramedics on the detection and treatment of tension pneumothorax, the rate of tension pneumothorax untreated by rescue services decreased from 1.35% (10 of 740 patients) to 0.4% (4 of 1034) [30].

Diagnosed Pneumothorax

A large pneumothorax, which can be assumed with typical auscultation findings, is a basic indication for evacuation of the pleural cavity. Whether this needs to be done in the pre-hospital setting or in the hospital is difficult to decide for individual cases. The risk of progression from simple to tension pneumothorax as well as the time this takes is variable and difficult to estimate. The literature offers neither general data on the topic nor risk factors. There is evidence that tension pneumothorax is found on admission to the Emergency Department more frequently in cases of chest trauma that have been intubated versus non-intubated patients.

Overall, it seems plausible to the experts that pneumothorax diagnosed by auscultation in ventilated patients has markedly higher risk to develop tension pneumothorax, and thus an indication for pre-hospital decompression.

If a patient with pneumothorax diagnosed on auscultation is not ventilated, the risk for developing tension pneumothorax appears to be much less. In a series of 54 cases of trauma-induced pneumothorax, 29 were treated conservatively, i.e. without chest tube placement. These patients were not mechanically ventilated, and most had no accompanying injuries. Chest tube drainage was placed in only two cases, as a result of radiologically progressing pneumothorax six hours after hospital admission [81]. In this case, pre-hospital decompression appears unnecessary (over expectant therapy with close monitoring and clinical controls). Due to the potential risks of pre-hospital decompression, in such cases it should only be carried out with strict consideration of risks versus benefits.

If appropriate monitoring and clinical controls are not easily possible, e.g. during helicopter transport, there is a certain, unquantifiable risk that tension pneumothorax could develop and that this would not be noticed in time or adequate therapy would not be possible due to space limitations. In such situations, when appropriate clinical signs are present and according to individual circumstances, pneumothorax decompression may be required for non-intubated patients prior to transport.

Chest Trauma Without Direct Diagnosis of Pneumothorax

If there are equal breath sounds bilaterally, the presence of clinically relevant pneumothorax is very improbable. In this case, there is no indication for pre-hospital decompression or pleural space evacuation, even when there is other evidence of chest trauma (not specific for pneumothorax).

A systematic review [137] found that the incidence of pneumothorax is relatively low (10 to 50 %) even when chest trauma is present. Thus, if an invasive intervention is carried out for a diagnosis of chest trauma alone without concrete evidence of pneumothorax, at least every second patient and up to nine of ten patients would be treated unnecessarily. Since cases of occult pneumothorax, only detectable on CT, were also included in this study, the rate of pneumothoraxes requiring evacuation was low. Even when pneumothorax was suspected due to specific clinical signs, the rate of unnecessary needle decompression and chest tube evacuation was between 9 and 65 % [8, 15, 124].

Thus, for individual cases with grounds, in ventilated patients with unmistakable signs of thoracic trauma but unsuspicious auscultation findings, decompression can be performed prior to longer transports or helicopter transport with limited clinical monitoring or treatment options. The high rate of false positive diagnoses for chest trauma by the emergency physician must be considered.

Under these conditions, decompression is not indicated in non-ventilated patients.

Hemothorax

The only general indications for pleural drainage/decompression in the acute pre-hospital setting are tension pneumothorax and massive hemothorax. The management of pneumothorax has been characterized above. Although hemothorax is a basic indication for pleural evacuation, there is generally no direct danger of compression from this blood and thus, no indication for pre-hospital drainage. Only in cases of massive bleeding, possibly with the development of a problem such as a tension pneumothorax, would emergency drainage be indicated. However, such situations would generally be associated with abnormal auscultation and thus, would proceed as in the case of pneumothorax. In the pre-hospital setting it is typically difficult to differentiate hemothorax from hemopneumothorax. Clinical signs of hemothorax versus pneumothorax would be dullness versus hyperresonance to percussion, provided the ambient conditions enable differentiation. Ultrasound examination can differentiate the two.

Therapy

Methods

The goal of treatment is decompression of the positive pressure in tension pneumothorax or tension hemothorax. The second goal of treatment is to avoid development of a tension pneumothorax from simple pneumothorax. Permanent and thorough evacuation of air and blood is not important in the pre-hospital setting.

Key Recommendations:

1.41	**Recommendation**	**Modified 2016**
GoR B	**Tension pneumothorax should be decompressed with single needle decompression. Surgical opening of the pleural cavity should follow, with or without chest tube placement.**	
1.42	**Recommendation**	**2011**
GoR B	**When indicated, pneumothorax should be treated with chest tube placement.**	

Explanation:

Because there are no suitable comparisons of data from the three methods (needle decompression, surgical opening of the pleural space alone, opening of the pleural space with immediate chest tube drainage), there can be no evidence-based recommendations for one method over another. For all three methods, there are (predominantly retrospective) data, case series, and case reports available that demonstrate that successful decompression of tension pneumothorax is possible.

Pathophysiologically, for sustained decompression it is necessary that the amount of air expelled into the pleural space with each inhalation also exits through the decompression device (regardless of which method has been chosen, thus needle or chest tube). The diameter with x4 then joins flow resistance. Thus, needle decompression (and even single chest tube placement) could remain ineffective, e.g. in tracheobronchial injury.

With the low level of evidence regarding the various methods, and to directly compare the different methods according to risk-benefits profile, the individual abilities of the treating emergency provider should also be taken as a practical consideration. One investigation reported a significantly reduced complication rate after chest tube placement by surgeons versus emergency physicians [61]. A more current study in North America also reported lower complication rates in resident physicians training in surgical versus non-surgical specialties [11]. The extent to which these results are transferable to the German emergency physician system cannot be evaluated due to the lack of reliable data.

Chest Tube Drainage: Effectiveness and Complications

Chest tube insertion is an appropriate, highly effective (> 85 %), but complication-ridden intervention to decompress tension pneumothorax, which must be applied particularly when alternative measures fail or prove inadequate. Typically, it offers definitive treatment and has the highest success rate. In 79 to 95 % of cases, chest tube drainage placed in the pre-hospital setting was the definitive and successful intervention [10, 51, 115].

Conversely, chest tube drainage has a failure rate of 5.4 - 21 % (mean 11.2 %) due to misplacement or insufficient effectiveness. Need for additional chest tube placement occurred with the same frequency [10, 33, 44, 51, 61, 70, 115, 124]. Affected cases were roughly equally divided between pneumo and hemothorax. Persisting tension pneumothorax was also observed in individual cases of chest tubes placed in the pre-hospital setting [10, 29, 98]. In addition to tube misplacement, this condition can occur in rare cases of a highly productive bronchopulmonary air fistula, which exceeds the discharge capacity of the established chest tube (e.g. in cases of large parenchymal tears or injuries to larger bronchi).

The pooled complication rates for chest tube drainage placement for pre-hospital versus hospital placement show increased complications in the former for subcutaneous placement (2.53 vs. 0.39 %), intraparenchymal misplacement (1.37 vs. 0.63 %), and intra-abdominal misplacement (0.87 vs. 0.73 %). Conversely, the infection rates are reversed (0.55 vs. 1.74 %) [52, 137]. Two studies directly comparing the complication rates pre- and in-hospital at the same institution [129, 141] found comparable infection rates (9.4 vs. 11.7 %) and misplacement (0 vs. 1.2 %). Duration of drainage placement was comparable in both groups. A current study of chest tubes placed in the emergency department found that 70 % of patients suffered acute and 40 % delayed complications [127]. In addition to retroperitoneal misplacement (1.1 %), intercostal artery injury (1.1 %), persisting pneumothorax (12.2 %) and over-advancement of the drain (33.3 %), 38.9 % of patients suffered pneumothorax recurrence with the chest tube in place, and more seldom (each 2.2 %) pleural empyema or local infection at the entry site. Another study observed a complication rate of 22.1 % [102].

In addition, for anterior to mid-axillary line chest tube drainage insertion, case studies have reported injury to the intercostal arteries [31], lung perforation [63], perforation of the right atrium [32, 100, 128], the right ventricle [117], and the left ventricle [47], subclavian artery stenosis from internal pressure of the drainage tip [107], ipsilateral Horner syndrome from drain pressure on the apex of the stellate ganglion [21, 29], intra-abdominal misplacement [62], perforation of the liver [45], the stomach [6], and the colon [1] in case of diaphragmatic hernia, a lesion of the subclavian vein, perforation of the inferior vena cava [60], and provocation of atrial fibrillation [13].

With insertion at the mid-clavicular line, there have been reports of subclavian vessel fistula [42], cardiac wall perforation [54], and perforation of the right atrium [100]. Other known complications include perforations of the esophagus, the mediastinum with creation of contralateral pneumothorax, phrenic nerve injury, etc.

Simple Surgical Opening: Effectiveness and Complications

Simple surgical opening of the pleural space is an appropriate, effective, and relatively simple measure to decompress a tension pneumothorax. However, it is only appropriate for patients receiving positive pressure ventilation, because only they have constant positive intrapleural pressure. In spontaneously breathing patients, negative intrapleural pressure is created, which can then suck air through the thoracotomy into the thorax.

Clinical experience shows that air is released when the pleural space is opened with a mini-thoracotomy for chest tube placement to decompress pneumothorax or hemothorax. Symptoms can improve dramatically in cases of a tension pneumothorax with hemodynamic effects. This technique was evaluated in the pre-hospital setting in a case series of 45 patients and was found to be effective without major complications [48]. In a prospective observational study of an air rescue system over two years, 55 patients with 59 suspected cases of pneumothorax were treated with simple surgical opening. The average arterial oxygen saturation increased from 86.4 % to 98.5 % as a result of the procedure. On surgical opening, either pneumothorax or hemothorax was found in 91.5 % of patients. Recurrent pneumothorax was not observed by these authors, nor any other serious complications (significant bleeding, lung laceration, pleural empyema) [96].

However, another series found relevant complications in 9 % of patients, in whom almost half of the cases had to do with non-decompressed or recurrent (e.g. through overlapping layers of soft tissue) tension pneumothorax [9]. Thus, insertion of chest tube drainage through the existing mini-thoracotomy is indicated in hospital.

Needle Decompression: Effectiveness and Complications

Needle decompression is an appropriate, frequently effective (approximately 32 - 53 %), simple, but not complication-free drainage procedure. If the effects are absent or insufficient, surgical decompression and/or chest tube insertion must be performed immediately.

The problem with clinical studies in the pre-hospital setting is the lack of scientific certainty that tension pneumothorax was actually present prior to needle decompression, which makes it difficult to judge effectiveness. With a pig model, the failure rate was 58 %, either because within five minutes a secondary malfunction occurred (bending, blockage, displacement) or because the pressure release was not sufficient [94].

In pre-hospital studies, needle decompression yielded air in 32 - 47 % of cases [15, 46]. Clinical improvements were seen in 12 to 60 % of patients in whom needle decompression was performed [15, 46, 58].

In contrast, one prospective series of 14 patients (five further patients died in the Emergency Department and were unsuitable for analysis) after needle decompression found eight patients without evidence of pneumothorax, two patients with occult pneumothorax, two patients with persistent pneumothorax, one case of successfully decompressed tension pneumothorax, and one case of persistent tension pneumothorax [43], so that of 14 patients only one clearly benefited.

In the Barton [15] study, needle decompression needed to be supplemented with chest tube placement in 40 % of cases (32 of 123) because of insufficient effectiveness. In other pre-hospital studies [37, 46], chest tubes were needed after needle decompression in 53 - 67 % of cases.

In one study, needle decompression did not work at all in 4.1 % of verified cases of pneumothorax, because the needle could not be placed deep enough. In 2.4 % of cases there was secondary needle displacement and in 4.1 % it was too difficult to place. No organ injuries were reported [15]. Another study found that needle decompression was unsuccessful in 2 % of patients because the needle was not deep enough. In another 2 % there was no indication and iatrogenic pneumothorax was the result. There were no infections or vascular injuries [58]. However, other investigators reported individual cases of lung injury [46] or cardiac tamponade [28]. Another group reported three patients with severe bleeding requiring thoracotomy [118]. In addition, several case reports and series have discussed needle decompression failure [26, 80]. The most probable cause is insufficient needle length. In individual cases, unilateral or bilateral tension pneumothorax was not identified in patients with chronic obstructive pulmonary disease (COPD) or asthma, in whom the entire lung was not collapsed [74, 104].

Needle Decompression versus Pleural Drain (Tension Pneumothorax Only!)

In two studies, needle decompression required significantly reduced overall treatment time, about five minutes, at the accident scene compared to chest tube placement (20.3 vs. 25.7 min) [15, 46]. More important than the overall treatment time is the duration between the recognition of the need for decompression and the successful implementation. Even for an experienced team with a trained provider, needle puncture is the fastest possible intervention. This applies even more so when optimal conditions do not exist for the treating team and there is no normal routine for chest tube placement. Therefore, needle decompression is recommended as the primary and most rapid intervention for life-threatening tension pneumothorax. Also, needle decompression is well suited as a primary procedure in cases where tactical use for trapped patients or adverse ambient conditions, e.g. subway tunnels, is called for.

When needle decompression is not successful on the first try, a second attempt should not be made. Possible causes of failure can include insufficient needle length, wrong puncture site, or misdiagnosis. The chances of success for a second attempt thus appear low. Instead, immediate surgical opening of the pleural space, if necessary with chest tube placement, must be performed, since the indication for decompression of the tension pneumothorax persists and may be more urgent. Essential to the effective treatment of tension pneumothorax is the surgical opening of the pleural space, through which the positive pressure can be released. Chest tube placement is a definitive air release and offers the best prophylaxis against recurrence.

For obese patients, primary surgical opening should be considered.

The guideline members believe that definitive treatment with surgical opening of the pleural space (mini-thoracotomy) and chest tube placement should be performed even after successful needle decompression. The reasons for this are possible displacement, bending, or obstruction of the needle during further therapy, transfer, or transport as well as insufficient decompression in cases with large fistula volumes under positive pressure ventilation. This assessment was confirmed in a study with 47 pre-hospital needle decompressions [55]. In 85 % of cases, secondary chest tube drainage was necessary for persistent symptoms, pneumothorax on standard x-rays, or relevant pneumothorax on CT. When possible, this should be performed in the pre-hospital setting. When there is an indication for urgent transport (e.g. profuse bleeding) or the emergency physician is less experienced, transport with readiness for chest tube placement can be considered.

Implementation

Needle Decompression: Puncture Site and Needle Length

There is no available evidence regarding the type or diameter of cannula to be used. Generally, the largest possible cannula diameter (14 or 12G) is recommended to allow the maximum amount of air to be released.

Some authors recommend needle decompression in the 2nd to 3rd intercostal space in the mid-clavicular line [15, 39, 43, 58], while others recommend using the 5th intercostal space in the anterior to mid-axillary line [22, 40, 118].

Table 9: Average Chest Wall Thickness according to CT chest in millimeters (range in brackets) of the 2nd intercostal space in the mid-clavicular line (2nd ICS in the MCL) and of the 4th or 5th intercostal space in the anterior or mid-axillary lines (4th-5th ICS in the A/MAL). The larger thickness value of the body side/gender was used for each case

Study	Chest Wall Thickness 2nd ICS in the MCL	Chest Wall Thickness 4th-5th ICS in the A/MAL
Akoglu [3]	Males: 38.8 ± 13.9	Males: 32.7 ± 13.9
	Females: 52.0 ± 18.4	Females: 39.3 ± 15.6
Bristol * [25]	30 ± 15.9	32 ± 14.7
Chang [34]	46.7 (17.8-98.7)	39.9 (13.6-116.6)
Givens [65]	41.6 (22-82) #	-
Harcke [68]	54.0 ± 11.9	-
Inaba [78]	46.0 (22.5-93.4)	32.9 (11.9-103.3)
Powers [116]	63.0 ± 19	-
Sanchez [123]	46.3 (CI 44.3-48.3)	63.7 (CI 61.1-66.3)
Schroeder [126]	40.8 ± 14	45.5 ± 17
Zengerik [142]	39.0 ± 14.2	-

* Cadaver study

in males; in females 49.0 mm

Table 10: Average Theoretical *Failure Rate* using CT Chest to reach the pleural space from the 2nd intercostal space of the mid-clavicular line (2nd ICS in the MCL) and from the 4th or 5th intercostal space along the anterior or mid-axillary lines (4th-5th ICS in the A/MAL)

Study	Needle Length (mm)	Failure Rate 2nd ICS in the MCL	Failure Rate 4th-5th ICS in the A/MAL
Akoglu [3]	50	up to 54 %	up to 33 %
Chang [34]	80	34 %	4 %
Givens [65]	50	25 %	-
Inaba [78]	50	43 %	17 %
Powers [116]	50	25-93% *	-
Sanchez [123]	50	30 %	53 %
Schroeder [126]	45	30 %	45 %
Zengerik [142]	45	19% (males) 35 % (females)	-

* in relation to BMI (< 18.5 vs. > 30.0)

A number of studies have assessed determination of chest wall thickness, mostly based on CT scans of the thorax (Table 9). Although some studies have found that the chest wall was thinner in the 2nd intercostal space along the mid-clavicular line than in the 4th or 5th intercostal space along the anterior or mid-axillary lines, other studies have reported the opposite. **Thus, from these studies there is no clear recommendation for one or the other puncture site.**

According to the measured chest wall thickness, the theoretical success rate of a needle decompression should be a function of the length of needle used (Table 10).

In one of the few studies that actually investigated the effectiveness of different needles of varying lengths, CT or ultrasound investigations showed residual pneumothorax in 65 % of patients in whom a 32 mm needle was used versus 4 % when a 45 mm needle was used [12].

In general, the average chest wall is 5 to 15 mm thicker in women than in men. Chest wall thickness typically correlates to body mass index [34, 78, 116]. The failure rate of 50 mm needles was 43 % in patients with normal body weight (BMI 18.5-24.9) and 89 % in highly obese patients (BMI> 30) [116].

There is very little evidence regarding the complication rate according to puncture site and needle length. In a study of CT chests of trauma patients, the theoretical success rate as well as the shortest distance to vital structures was estimated with an 8 cm puncture needle [34]. In this study, various needle lengths and puncture sites were assessed on chest CT regarding possible complications from iatrogenic lesions. The average distance from puncture site to the nearest vital structure (regardless of insertion angle) in the 2nd ICS MCL was 114 mm and in the 4th-5th ICS in the anterior axillary line was 109 mm. Using an 80 mm needle, 32 % of cases could have resulted in injuries to vital structures (usually the left ventricle). If the needle was inserted perpendicular to the skin surface, however, the rate of potential injuries would decrease to 9 %. In other sites, the potential injury rate was $\leq$ 9% with an 80 mm needle and $\leq$ 1% for a 50 mm needle. The pleura was reached for each puncture site in 96-100 % of cases with the 8.0 cm needle, and only 66-81 % of cases with the 5.0 cm needle. Thus, the lower complication rate is also associated with a higher risk of failure.

A current meta-analysis including 18 studies determined that the pleura would be reached in 95 % of cases with a needle length of 6.44 cm, and thus, use of a 6.5 cm needle was proposed [36]. However, there is no clinical evidence of an actually improved success rate or possible increase in puncture complication rates.

Experts say that the risk of lung injury from adhesions after a lateral approach is greater, and air in the pleural space is more likely found towards the apex. Whether these assumptions are a good argument to use the mid-clavicular line cannot be said, because there are no investigative results available. An investigation on models found that with an anterior puncture site, there is a strong tendency for the puncture site to occur medial to the mid-clavicular line, with associated risks of injuring the heart, the internal thoracic or the large vessels [109].

There are no investigations directly analyzing the actual risks and benefits for the use of longer versus normal needles. The risk of injuring a vital structure with a 45 or 50 mm needle appears very low; however, the failure rate is over a third of cases. With a longer needle (80 mm), successful decompression appears much more likely, but it is also associated with greater risks of injuring vital structures, particularly in left sided punctures from a lateral approach. Some experts thus advise the use of standard needles (4.5 cm) followed by surgical opening of the pleural space (mini-thoracotomy) in cases without success. In the military sphere, however, 14 G needles measuring 8.9 cm (3.5 inches) or 8.2 cm (3.25 inches) are used routinely [73] [49, 108]. These needles are specially designed for pleural decompression, as opposed to intravenous cannulas used for this indication. **With the data currently available, a general recommendation regarding needle length cannot be given**. Depending on education and training level, among other things, of the rescue provider performing the needle decompression, a balance must be found between increased success rates and decreased injury rates. In cases of resuscitation (and similarly threatening situations), it may be preferable to choose the longer needle, as the risk-benefit ratio is clearly shifted.

Chest Tube Drainage: Tube Placement and Size

Recommendations for placement for pleural evacuation drains are either in the 4th to 6th intercostal space in the anterior to mid-axillary line [39, 131, 135] or in the 2nd to 3rd intercostal space in the mid-clavicular line. The nipple is an orientation point. Puncture should not occur beneath this point, because below the nipple the risks for abdominal misplacement and abdominal organ injury increases. In women with larger breasts, the submammary fold (where the wire of the bra usually lies) can be used as the orientation point. Another method is one hand width below the axilla, using the hand width of the patient. It is important to note that the puncture site should always be between the ribs. The skin incision can also be a bit inferior to the intercostal space (see Implementation section).

Complications have been published for both puncture sites in clinical case reports. One prospective study found no influence of the level of puncture (2nd to 8th ICS) or the lateral positioning (MCL or MAL) on the success rates regarding decompression of pneumothorax or hemothorax after penetrating trauma [56]. A cohort study analyzed the complications for chest tubes placed in the 2nd to 3rd intercostal space in the mid-clavicular line (n = 21) and in the 4th to 6th intercostal space in the anterior axillary line (n = 80) [75]. Although the rate of interlobar misplacement is significantly higher with a lateral approach, rates of functional misplacement from both sites were comparable (6.3% vs. 4.5%). In contrast, a Japanese study [97] reported significantly lower rates of residual pneumothorax (22 vs. 64 %) and functional misplacement (6 vs. 43 %) with an anterior approach. **A recommendation for a preferable puncture site cannot be given, even if an anterior approach is at least as favorable as the lateral.**

Even a thin drain should suffice for pneumothorax decompression. In cases of non-traumatic pneumothorax, 75-87 % of patients were successfully treated with size 8-14 French (Fr) chest tubes [41, 95]. A study of patients with pneumothorax after isolated thoracic trauma found a success rate of 75 % with thinner catheters (8 Fr). The remaining 25 % required insertion of a large lumen chest tube [50]. One case study reported the progression of simple to tension pneumothorax despite an indwelling 8 Fr tube. This was a mechanically ventilated patient with a ruptured emphysematous bulla [17].

Because at least 30 % of trauma cases are combination hemopneumothorax, it is feared that a thin chest tube can be too easily blocked. For this reason, use of 24-32 Fr tubes is suggested in adults [16, 77, 131, 135]. This recommendation was confirmed with a current prospective observational study [79]. In 353 cases overall, there was no disadvantage regarding size of a retained hemothorax or need for extra tube placement when thinner tubes (28-32 Fr) were inserted. A randomized study [140] treated patients with isolated hemothorax (without pneumothorax, unilateral, without coma or sedation, coagulopathy, etc.) either with conventional chest tube drainage or with central venous 16G catheter. Success and complication rates were comparable. Another randomized study of patients with traumatic uncomplicated pneumothorax by Kulvatunyou et al. [85] had similar results. This study, however, included only patients who were conscious and cooperative, without urgent need of decompression. Complication and success rates were comparable, but the 14 Fr pigtail catheter was less painful than the 28 Fr chest tube. The same group reported similar good experiences with drainage of hemothorax [86].

Because of general experience with blood clots blocking small-lumen catheters, these studies should be considered critically. Additional studies are needed before recommendations regarding the use of small lumen tubes to decompress hemothorax can be included or given, especially since the patients in these studies were stable, non-ventilated patients. It's possible that such patients can be adequately treated with less invasive catheters.

Implementation (Needle Decompression)

Controlled studies have not investigated the best technique, so this section is according to expert opinion. It is important to choose the correct puncture site, because there is a tendency to puncture medial to the mid-clavicular line [109]. An in-dwelling venous cannula with an attached syringe set to aspirate should be inserted in a straight path until air is aspirated [39]. Once the pleural space has been reached, the steel stylet should be left in place to prevent kinking of the unprotected plastic cannula [43, 112]. Some authors argue that the stylet should be withdrawn several millimeters or removed completely, leaving only the plastic cannula in place [58, 109]. However, kinks in the cannula have been documented [109].

Implementation (Surgical Decompression and Chest Tube Drainage)

Key Recommendations:

1.43	Recommendation	2011
GoR B	The pleural space should be opened by mini-thoracotomy. Chest tubes should be placed without a trocar.	

Explanation:

Controlled studies have never assessed the best technique. Most experts recommend a standardized procedure as follows. Chest tubes must be placed using sterile technique. After skin disinfection, local anesthesia will be applied to the level of the parietal pleura to patients who are not deeply unconscious. A horizontal skin incision approximately 4-5 cm in length is made with a scalpel along the upper border of the rib below the intercostal space to be punctured, or one rib deeper (for cosmetic reasons, this should be done at the appropriate level in the sub-mammary fold for women). The subcutaneous tissues and the intercostal muscles on the upper rib border are opened with blunt scissors or a clamp. The pleura can be separated by blunt dissection or using a small cut with the scissors. Next, a finger (sterile glove) is inserted into the pleural space to verify the correct approach and to ensure a lack of adhesions or release any adhesions present [16, 48, 103, 121, 131, 132, 135]. If a simple thoracic opening is desired, the wound is then covered with a sterile dressing, left untaped on one side (for venting).

If a chest tube drain is to be inserted, the procedure continues as follows. A subcutaneous tunnel is not considered necessary by all experts [132]. Blind preparation of the passage with a trocar should never be performed. Serious complications have been reported with this, such as perforation of the left ventricle, the right atrium in a patient with kyphoscoliosis [100], or the lungs [63]. The complication rates in studies of the trocar technique are much higher than those evaluating surgical technique (11.0 % vs. 1.6 %). A prospective cohort study (in intensive care patients) reported that the use of a trocar was associated with significantly higher rates of misplacement [119]. Some experts recommend that ventilation should be paused briefly at the moment of pleural separation and tube insertion to reduce the risk of parenchymal injury in the inflated lung [63, 113, 114].

The chest tube is then inserted through the prepared channel. A finger can be inserted as well to guide the tube. The tip of the tube can also be held and inserted with a clamp. Alternatively, a trocar can be used to guide the tube (not for preparation or for perforation of the thoracic wall!). When doing this, it is important that the tip of the trocar does not protrude beyond the tip of the drain, and that no force is applied while the tube is advanced [135].

It is unclear how the tube tip should be positioned. Generally, recommendations are that the tube tip should be directed posterior/caudal for hemothorax and anterior/cranial for pneumothorax. This doctrine was challenged in a recent study, in which the drain position had no influence on success rate (drainage of air and blood) [19].

To avoid displacement, the tube must be secured with steri-strips or a suture. A self-locking plastic loop can also be used for fixation [101].

Alternative Insertion Techniques

Alternative insertion techniques have not been used much in the pre-hospital setting. There is a lack of studies for the pre-hospital setting, particularly studies comparing to standard technique. Two techniques (Seldinger technique, Veres needle) must be briefly discussed.

Use of a laparoscopic trocar cannula has been well studied compared to other alternative techniques, but has not been directly compared to the standard surgical technique [18, 64, 82, 92, 136]. A prospective cohort study including 112 patients, 39 of them trauma patients, compared techniques and complications [136]. The only complication was lung injury (0.89 %). In a pig model, the technique with a Veres nail had a 100 % success rate within an average 70 seconds, versus a classic 14G needle with 21 % success within 157 seconds. Puncture-related injuries to the internal organs were not seen with either method [69, 91].

In 1988, Thal and Quick described a technique of inserting a guidewire after direct puncture, then expanding the canal with progressive dilators and eventual inserting the chest tube (to 32 Fr) over the guidewire [111, 133]. The patient had initial success in 24 pediatric patients (14 pneumothorax, three hemothorax, seven other). Kinking of the catheters (10-20 Fr) occurred in five cases (approximately 20 %) [2]. A systematic review found no advantage for the Seldinger technique over other techniques [7].

Drainage Systems

Suitable collection systems are also commercially available for pre-hospital use. An ideal system, in which positive pressure cannot develop, should have an appropriate valve, an indicator for the presence of an air fistula, and a sufficiently large reservoir to collect blood or secretions. Systems that operate only in upright or hanging positions seem impractical, since this cannot be guaranteed at all times, particularly during transport. For use in the pre-hospital setting, systems not requiring the additional filling with water are preferable. Systems using bags have the advantage over bottles or containers, since they require less space.

Reliable data regarding the question of whether and when chest drainage can be left open or not, and which collection system should be used are not available. Thus, a strong, evidence-based, uniform expert recommendation cannot be given. However, it seems that the commercially available thorax drainage bags with pressure-relief valves are the most appropriate in fulfilling all of these requirements, even if there have not been published sustainable clinical results.

No Closure

Theoretically, for patients receiving pressure ventilation, the chest drainage could be left open. In such cases, there would be a higher risk of contamination of the pleural space with subsequent pleural empyema. A potentially increased risk for the transmission of infectious diseases to the emergency personnel and contamination would occur with unprotected leakage of blood from the tube.

In spontaneously breathing patients, however, there would be the danger that on inspiration, air could be sucked into the pleural space and lead to lobar collapse. In this situation, the tube cannot remain open to the outside, and addition of a valve mechanism is necessary.
For these reasons, leaving the chest tubes open is not recommended.

Heimlich Valve
One commercially available valve device is the Heimlich valve. It was originally used to decompress spontaneous pneumothorax in spontaneously breathing patients [20]. In one of 18 cases, the valve stuck and no longer worked. In a retrospective comparison, the 19 Heimlich valve patients had shorter drainage and hospitalization times than 57 patients treated with a standard drainage system (one third of the patients had traumatic pneumothorax). However, patients with hemothorax were excluded and four patients in the Heimlich valve group transferred to the control group [110]. Thus, it's unclear whether this experience is transferable to the pre-hospital setting. Other case reports have found that the valve stuck, causing an outflow diversion and leading to recurrent tension pneumothorax [71, 93]. Heimlich valves were used routinely during the Falklands War, and it was reported that valves stuck frequently from clots and needed repeated replacement, without further quantification of the problems [138]. Experimental studies found that two of eight valves malfunctioned, and after exceeding the expiration date, seven of eight valves were defective [71]. In addition to material fatigue, coagulated blood can also lead to malfunction. Uncertainty regarding valve function leads to an incalculable risk potential, and close monitoring during its use is necessary. The same concerns apply to all other valves except for multi-bottle systems. Because of the risk of a stuck valve from blood clots, contraindication of Heimlich valves for hemothorax has been discussed [66]. Thus, Heimlich valves can no longer be recommended.

Closed Bag or Chamber Systems
Although the attachment of a closed collection bag can reduce the risk of contamination and infection, in cases where there is a large enough air fistula, filling of the bag with air or blood can lead to recreation of positive pressure and tension developing in the pleural space. Here, continuous observation and repeated bag emptying is necessary. One must fear that failure of the chest tube drainage through the reversed pressure ratios in a bulging collection bag, particularly in the pre-hospital setting, could be easily overlooked because the inserted chest tube suggests that the tension pneumothorax has already been successfully treated. Perforation of a primarily closed simple bag system to avoid positive pressure is strongly discouraged for hygienic reasons.

In hospital conditions, generally a derivative of a two or three chamber system is used, with mainly closed commercial collection systems in use. The advantages are the good functionality and the protection against environmental contamination with blood. They are also the definitive collection systems for further treatment in the hospital. In prehospital use, problems arise because they are awkward to handle when repositioning and during transport, and there is a resulting risk of overturning. Overturning can lead to uncontrolled displacement of the filling fluids between the chambers, risking functionality [67]. One major advantage of these systems, however, is the ability to place suction and to quantify the collected fluids.
The evidence table for this chapter is found on page 113 of the guideline report.

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1.5 Traumatic Brain Injury

Interventions at the Accident Scene
Vital Functions

Key Recommendations:

1.44	Recommendation	Modified 2016
GoR B	**In adults, the goal should be normal arterial pressure with systolic blood pressure not falling below 90 mmHg (age-adapted in children).**	
1.45	**Recommendation**	**Modified 2016**
GoR B	**Arterial oxygen saturation below 90% should be avoided.**	

Explanation:
Due to ethical considerations, prospective randomized controlled trials examining the effects of hypotension and/or hypoxia on treatment outcomes are not justifiable. However, there are many retrospective studies [9, 20] that provide evidence of markedly worse outcomes when hypotension or hypoxia are present. The absolute priority of diagnostic and therapeutic measures at the accident scene are thus, the recognition and, if possible, immediate elimination of all conditions associated with decreased blood pressure or blood oxygen saturation. However, aggressive therapy to increase blood pressure and oxygen saturation has not always been supported, due to adverse effects. The goals should be normal oxygen, carbon dioxide, and blood pressure levels.

Indications for intubation include insufficient spontaneous respiration and decreased level of consciousness with or without adequate spontaneous breathing. The major argument for intubation is the efficient prevention of secondary brain injury through hypoxia. This is a threat in unconscious patients even when there is adequate spontaneous breathing, since impaired reflexes can result in aspiration. The major argument against intubation is the hypoxic injury that can occur during an unsuccessful intubation. However, Bernard et al. reported a significantly higher percentage of good neurological outcomes (defined as 5 to 8 points on the extended Glasgow Outcome Scale, GOSe) six months after traumatic brain injury in patients with GCS ≤ 9 who were intubated at the accident scene [4].

Interventions to support hemodynamic stability in multiply injured patients are described elsewhere in this guideline (see Chapter 1.3). Specific recommendations cannot be made regarding the infusion solution to be used for volume replacement in multiply injured patients with traumatic brain injury [9].

Neurologic Examination

Key Recommendations:

1.46	Recommendation	Modified 2016
GoR A	**Repeated examinations and documentation of level of consciousness, pupillary function, and Glasgow Coma Scale must be performed.**	

Explanation:
In the literature, the only clinical findings with prognostic value are the presence of wide, fixed pupils [9, 19, 21] and deteriorations in the GCS score [9,13,19,21], both of which correlate with a poor treatment outcomes. There are no prospective randomized controlled trials on guiding treatment according to clinical findings. Since such studies are not ethically justifiable, during the development of this guideline, the importance of the clinical examination was raised to grade of recommendation A under the assumption (currently unconfirmable) that outcomes can be improved with the earliest possible detection of life-threatening conditions that have associated therapeutic consequences.

Despite various difficulties [3], the Glasgow coma scale (GCS) has established itself internationally as the assessment tool to estimate of the momentary severity of a brain injury/impairment. It enables a standardized assessment of eye opening, verbal response, and motor response. The neurologic findings, documented according to the time, are essential to the further course of treatment. Frequent checks of neurologic findings must be performed to detect any deterioration [9, 10].

However, the use of GCS alone risks a diagnostic gap, particularly if only total values are considered. This applies particularly to an early acute midbrain syndrome, which can manifest as spontaneous decerebrate rigidity, which is not recorded on GCS, or to associated injuries of the spinal cord. Thus, motor function of the extremities must be examined and recorded, with lateral differentiation of the arms and legs - whether complete, incomplete, or no paralysis is present. The presence of decorticate or decerebrate rigidity should be noted. If voluntary movements are not possible, all extremities should be examined for reactions to painful stimuli.

If the patient is conscious, then orientation, cranial nerve function, coordination, and speech must also be noted.

Neuroprotective Therapy

Key Recommendations:

1.47	Recommendation	2011
GoR A	**Glucocorticoid administration must be avoided.**	

Explanation:

According to current scientific understanding, the goals of interventions performed at the accident scene are to achieve homeostasis (normoxia, normotension, prevention of hyperthermia) and to prevent threatening complications. Secondary brain injury must be limited and optimal conditions must be provided for functional regeneration of injured but intact brain cells. This applies equally when multiple injuries are present.

To date, there has been no published evidence confirming the benefits derived from more extensive treatment regimens focused solely on neuroprotection. At present, no recommendation can be given for pre-hospital administration of 21-aminosteroids, calcium antagonists, glutamate receptor antagonists, or tris-(tris[hydroxy methyl]aminomethane) buffers [9,12,16,23].

Antiepileptic treatment prevents the incidence of epileptic seizures in the first week after trauma. However, the incidence of a seizure in the early phase does not lead to worse clinical outcomes [18, 20].

The administration of glucocorticoids is no longer indicated due to a significantly increased 14-day mortality [1, 17] with no improvements in clinical outcome [8].

Therapy for Suspected Severely Elevated Intracranial Pressure

Key Recommendations:

1.48	Recommendation	Modified 2016
GoR 0	**In suspected cases of severely increased intracranial pressure, particularly with symptoms of transtentorial herniation (pupillary dilation, extensor synergy, extensor reflex to pain stimulation, progressive disorientation), the following measures can be applied:** **•Hyperventilation** **•Hypertonic saline** **•Mannitol**	

Explanation:

In cases where transtentorial herniation is suspected and there are signs of acute midbrain syndrome (pupillary dilation, decerebrate rigidity, extensor reaction to painful stimuli, progressive loss of consciousness), hyperventilation can be initiated in the early phase after trauma [9, 20]. The reference value is 20 breaths per minute in adults and must be adapted for children according to age. Hyperventilation was often used in the past because of its often impressive effects in reducing intracranial pressure. However, because of associated vasoconstriction, it also reduces cerebral perfusion. Thus, aggressive hyperventilation involves a risk of cerebral ischemia and with it a worsening in clinical outcomes [20].

Administration of mannitol can reduce intracranial pressure (ICP) for a short time (up to one hour) [20]. When transtentorial herniation is suspected, it can be given without ICP measurement.

To date, there is little evidence that hypertonic saline solutions are neuroprotective. Mortality appears somewhat less than mannitol. However, this conclusion is based on a small number of cases and is not statistically significant [22].

In the time since the first version of this guideline was published, there has been no new evidence that mannitol or hypertonic saline solutions lead to better clinical outcomes in severe TBI [6, 14]. Unfortunately, there are no meaningful studies to date regarding this specific question (measures to combat suspected transtentorial herniation). One newer study [7] shows effects on ICP by both infusion solutions. Methodological weaknesses (small population, unclear statistics without confidence intervals, variation in GCS between the groups) limit the relevance of the study. Nevertheless, based on pathophysiological considerations, an optional recommendation for these interventions appears to be justified when there is clinical suspicion of severely increased ICP also at the accident scene or during transport. Since there are no clear differences in the effectiveness of mannitol and hypertonic saline solutions, the change in the order of recommendation is based principally on the relative ease of storage for hypertonic saline (see the "Hypertonic Solutions" section).

Although barbiturates have been recommended in previous guidelines for otherwise-uncontrollable increases in ICP [11], there is insufficient evidence for their use [15]. When barbiturates are administered, attention must be given to the negative inotropic effects, possible hypotension, and impaired neurological assessment.

Transport

Key Recommendations:

1.49	Recommendation	2011
GoR B	**In cases of penetrating injuries, the perforating object should be left in place, or removed if necessary.**	

Explanation:

It is essential that polytrauma patients with symptoms of accompanying traumatic brain injury be admitted to a hospital with adequate treatment facilities. In cases of TBI with persistent unconsciousness (GCS $\leq$ 8), increasing confusion (deterioration of individual GCS values), pupillary changes, paralysis, or seizures, the treating hospital should definitely provide neurosurgical treatment for intracranial injuries [9].

No clear recommendations can be given regarding analgesia or relaxation for transport, as there is a lack of studies showing positive effects for TBI. Cardiopulmonary issues are much easier to manage with such measures; thus, the decision must be left to the judgment of the treating emergency physician. The disadvantage of this is the more or less severe limitations to neurologic assessment [20].

In cases of penetrating injuries, the perforating object should be left in place, or removed if necessary. Injured intracranial vessels are often compressed by the foreign body, so that removing it encourages the development of intracranial bleeding. Thus, removal must be carried out under surgical conditions with the ability for hemostasis in the injured brain tissue. Although there are no prospective randomized controlled studies on the optimal procedure for penetrating injuries, this approach makes sense from a pathophysiological perspective.

During transport, the possibility of accompanying unstable spine fractures should be considered and appropriate positioning applied (see Chapter 1.6).

Teeth and Tooth Fragments:

Key Recommendations:

1.50	Recommendation	New 2016
GPP	**Avulsed teeth and tooth fragments should be collected, stored in a moist environment, and brought to the trauma center for re-implantation.**	

Explanation:
This can be carried out in a container with a specific cell-friendly solution, Ringer's, or UHT milk [2, 5].

The evidence table for this chapter is found on page 122 of the guideline report.

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1.6 Spine

When should a spinal injury be presumed?

Which diagnostic interventions are necessary?

Key Recommendations:

1.51	**Recommendation**	**2016**
GoR A	**A targeted physical examination including the spine and related functions must be performed.**	

Explanation:
Evaluation of the accident mechanism can give indications as to the probability of a spine injury [7]. Thus, the probability for these injuries increases with falls from a height and high-speed accidents [18].

Once the vital functions have been checked and secured in a conscious patient, examination of the spine at the accident scene includes an orienting neurological examination with sensory and motor components. A neurological deficit can indicate a spinal cord injury. Absence of back pain is not an exclusion criterion for relevant injury to the spine [17].
Inspection (signs of injury/deformity) and palpation (tenderness to pressure/palpation or palpable step deformity/gaps between the spinous processes) complete the examination.

Although there are no scientific studies regarding the importance and required scope for physical examination of the spine in pre-hospital emergency medicine, these examinations remain indispensable for diagnosing potential spinal injuries. All of the investigations listed above serve to detect relevant, threatening or potentially threatening disorders and injuries that taken together can necessitate immediate and specific therapy or logistical decisions [6, 39].

Which associated injuries make a spinal injury more probable?

Key Recommendations:

1.52	**Recommendation**	**2016**
GoR A	**In unconscious patients, spine injury must be assumed until there is evidence to exclude it.**	

Explanation:
There are particular injury patterns that are more commonly associated with spinal injuries. For example, there is a high incidence of spinal injuries in patients with relevant supraclavicular injuries or with severe injuries of other body regions [41].

How is the diagnosis of spinal injury made and how definite is it?

Explanation:
A number of groups have developed clinical decision-making rules to simplify the diagnosis of spinal injury and the indications for pre-hospital spine immobilization as well as to give structure to the primary radiological approach to potential spinal injuries after blunt trauma. Some of these decision-making rules have to do with the pre-hospital setting [13-15], and others with the emergency department [3, 18-20, 38].

The NEXUS Study [14, 29] formulated five criteria which, when lacking, make injury to the cervical spine unlikely.

- Impaired level of consciousness
- Neurological deficit
- Spinal pain or muscle tension
- Intoxication
- Extremity trauma

Application of these five criteria yielded a sensitivity of 95 % with a negative predictive value of 99.5 %. Another study concentrating on polytrauma patients with potential c-spine injuries [33] found similar predictors. Thus, generalization of the NEXUS criteria seems appropriate and, in our opinion, also applicable to the thoracic and lumbar spine.

Prospective studies by Bandiera et al. and Stiell et al. demonstrated that clinically significant injuries can be unmasked in unconscious patients with a sensitivity of 100 % by applying the Canadian C-spine rule [1, 38].

Neurological deficits are crucial for the diagnosis of spinal cord damage (sensory and motor). Whether it is a complete or incomplete lesion and the segment height of the injury can often be determined only to a limited extent in the pre-hospital setting.

How should a spine injury be treated in the pre-hospital setting?

What is the technical rescue procedure of a person with spinal injury?

Key Recommendations:

1.53	**Recommendation**	**Modified 2016**
GPP	**The cervical spine must be immobilized prior to the actual technical rescue during rapid and careful rescues. An exception is the need for immediate rescue (e.g. fire or risk of explosion).**	

Explanation:
The indications for spine immobilization during the technical rescue are based on patient condition. For example, in

cases of acute life-threatening danger (fire, need for resuscitation), immediate rescue (e.g., with a Rautek/fire-fighter's grip) can be performed without spinal immobilization. In cases of a rapid rescue, manipulation of the spine must be minimized; nevertheless, due to the patient's condition, short rescue time is the focus. For the cervical spine, immobilization should be carried out with a cervical collar, even though the research literature has not yet substantiated this procedure to avoid secondary damage.

Depending on patient condition, slower, careful rescue (e.g., with removal of a car roof) can be considered, during which strict spinal immobilization should be carried out.

Treatment aids, such as scoop stretchers or backboards facilitate rescue of patients with spinal injuries from adverse locations.

How should a patient with spinal injuries be positioned/ immobilized?

Explanation:

The first pre-hospital measure for someone injured in an accident should be c-spine immobilization manually or with a cervical collar, even though there is no high level of evidence for this. This places the c-spine in a neutral position. If this causes pain or increased neurological deficits, reposition to the neutral position should not be carried out. Neutral position of the c-spine can also be achieved with adults in the supine position by placing padding underneath the head [37].

Using a cervical collar alone allows some residual mobility of the c-spine. Better immobilization of the c-spine can be achieved with additional positioning on a vacuum mattress. This achieves the most effective immobilization of the entire spine. Incorporating the head with cushions or straps can further restrict possible residual movement of the c-spine. To date, no randomized studies have shown positive effects of spine immobilization [25]. Other aids such as a scoop stretcher provide only limited immobilization.

When traumatic brain injury is present and c-spine injury is suspected, the use of a rigid collar should be weighed with the risk of a potential increase in intracranial pressure [8, 11, 21, 23, 24, 31]. An alternative immobilization method is fixation of the patient in a vacuum mattress with upper body positioning and additional fixation of the head without the rigid collar.

How is a person with spinal injury transported?

Key Recommendations:

1.54	Recommendation	Modified 2016
GPP	**Transport should be as gentle and pain-free as possible.**	

Explanation:

A patient with spinal injury should be transported as gently as possible, i.e. without unnecessary external force, to avoid pain and potential secondary injury. After appropriate immobilization, analgesia can be administered for transport. A helicopter offers the smoothest form of transport. It also often offers a time advantage for patients with spine and neurological injuries who must be transported to a specialized center that is farther away.

Are there specific interventions to be performed in the pre-hospital phase for spinal injuries?

Explanation:

Currently, there is no evidence for meaningful treatment of spinal injuries in the pre-hospital setting. Pre-hospital administration of cortisone to patients with spine injuries and neurological deficits cannot be recommended according to the current body of evidence [2, 30]. In general, the goals should be adequate perfusion and oxygenation for patients with spinal injuries and neurological deficits. The diagnosis of neurogenic shock requires that hemorrhagic shock with hypovolemia has been excluded. The level of evidence of specific therapy for neurogenic shock is not high; however, volume replacement should be cautious considering the normovolemia of the patient, and vasopressors should then be favored.

Is it advantageous for a spinal injury patient to be transported primarily to a spine trauma center?

Key Recommendations:

1.55	Recommendation	Modified 2016
GoR B	**Patients with neurologic deficits and suspected spine injury should be primarily transported to an appropriate trauma center.**	

Explanation:

Various studies have found that operative treatment of spine injuries within 72 hours significantly reduces morbidity (ventilation time, incidence of pneumonia and pulmonary failure) as well as duration of intensive care and hospital admission [4, 5, 9, 22, 35, 36]. The most severely injured patients (ISS > 33) with thoracic spine injuries seem to benefit particularly [34]. Current evidence is inconclusive as to the extent that early decompression of spinal injuries with neurological deficits positively influences neurological outcomes [10, 12, 16, 28, 30, 32, 42]. However, several of these studies do show a positive trend for early decompression (although the definition of "early" varies according to study from 8 to 72 hours after trauma), particularly in cases where there are symptoms of incomplete cord lesions, without increasing the intraoperative complication rate [27, 43]. Neurological outcome was, however, correlated with the expertise of the trauma center in the treatment of spinal injuries [26].

Thus, particularly in isolated spinal trauma and when the patient's condition is not acutely life-threatening, the patient should be transported directly to an appropriate spine trauma center [40, 42].

Notes:
The references underlying these recommendations generally refer to in-hospital situations that, when relevant, were transferred to the pre-hospital setting. It should also be considered that the organization of pre-hospital care in certain countries varies considerably compared to the German emergency physician service (e.g. paramedics), which is why the results from the global literature are often not completely relevant to the situation in Germany.

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1.7 Extremities

Priority

Key Recommendations:

1.56	Recommendation	2011
GoR A	**Profusely bleeding extremity injuries that can impair vital functions must be given priority.**	
1.57	Recommendation	2011
GoR A	**The treatment of extremity injuries must avoid further damage and not delay overall rescue time in cases when other threatening injuries are present.**	

Explanation:
Securing vital signs and examination of the head and torso should precede examination of the extremities. Particular features nay be found in extremity injuries with severe blood loss [41, 52].

Severe and immediately life-threatening bleeding must be controlled immediately with appropriate positioning, compression, or tourniquet placement. For example, according to the ETC (European Trauma Course), this type of bleeding can be recognized and treated during the 5 second check.

The recognition of major external but not immediately life-threatening bleeding is important and is generally performed with the “C” (circulation), while minor bleeding is recorded during the secondary survey [41].

The highest priorities are to avoid further damage, to restore and stabilize vital functions, as well as to transport to the closest suitable hospital [20, 47]!
Management of extremity injuries (irrigation/wound care/splinting) should not delay rescue time when additional life-threatening injuries are present [44].

Diagnostic Studies

Medical History

An exact account of the circumstances of the accident (by the patient or a witness) should be collected with as much detail as possible to obtain sufficient information regarding the forces at work and when applicable, the grade of contamination for open wounds [5, 52].

In addition to the accident history and time of trauma, if possible, information should be gathered regarding allergies, medications, and previous medical history as well as time of the last meal. Tetanus immunization status should also be collected with the history [41, 60].

Examination

Key Recommendations:

1.58	Recommendation	2011
GoR B	**All extremities of an accident victim should be examined in the pre-hospital setting.**	

Explanation:
Conscious patients should be asked first regarding complaints and localization. If they are pain, adequate analgesia should be given early [41]. A pre-hospital examination should be performed [20]. At the accident scene, injuries should be evaluated enough to assess injury severity without unnecessary delay in overall rescue time [5]. It should be an exploratory survey from head to feet and not take longer than five minutes [60].

The examination should be performed in this order: inspection (deformity, wounds, swelling, perfusion), test for stability (crepitus, abnormal mobility, direct or indirect signs of fracture), assessments of circulation, motor function, and sensation. The soft tissues should also be evaluated (closed vs. open fractures, evidence of compartment syndrome) [20, 41, 52]. Capillary reperfusion can be compared bilaterally [41].

Leather clothing, e.g. motorcycle apparel, should be left in place as much as possible, since it serves as a splint with compression effects, especially for the pelvis and lower extremities [25, 41].

Treatment

General

Key Recommendations:

1.59	Recommendation	2011
GoR B	**Even in cases of suspected injury, the extremity should be immobilized prior to moving/transporting a patient.**	

Explanation:

Immobilization of an injured extremity is an important pre-hospital intervention. An injured extremity should be immobilized against rough motion and prior to patient transport. The reasons for this are to alleviate pain, to avoid further soft-tissue injury or bleeding, as well as to minimize the risk of fat emboli and neurological damage [41, 60].

Even suspected injuries should be immobilized [19, 60].

The joints proximal and distal to the injury should be included in the immobilization [19, 20, 46, 60]. The injured extremities should be supported in a flat position [10]. Particularly in cases of shortened femur fracture, traction/immobilization should be carried out under traction to minimize bleeding [5, 41]. Vacuum splints enable immobilization in abnormal positions. Vacuum splints are rigid and adapt to the shape of the extremity [41]. Air chamber splints are suitable to splint upper extremity injuries except for injuries around the shoulder joint. They are appropriate to immobilize lower extremity injuries of the knee, lower leg, and foot. Once applied, the air in the air chamber splints and the peripheral circulation must be checked regularly to recognize early any perfusion problems or development of compartment syndrome [10]. The time of splint application should be documented, for example noted on the splint itself. One advantage of the air splint is its low weight. The disadvantage is compression of the soft tissues, which can cause secondary damage. Thus, vacuum splints are preferred. Air and vacuum splints are both unsuitable for immobilization of fractures near the shoulder joint or femur fractures [11]. Cooling can reduce swelling and alleviate pain [19]. Femoral injuries can be adequately immobilized with a vacuum mattress or a rigid splint without complications. Traction splints can be applied by rescue workers.

A retrospective study with 4513 rescue calls by paramedics in the American Emergency Medical Service (EMS) identified 16 patients (0.35 %) with injuries of the mid-femur. While only minor injuries were diagnosed in eleven of these patients, five (0.11 %) were treated for femoral fractures. Traction splints were applied in three of these five patients. In one case, the traction splint needed to be removed because of excessive pain, and rigid immobilization was applied. One patient could not be treated with traction because of a concomitant hip trauma injury. One other patient was free of pain and transported in a comfortable position. The authors concluded that femoral injuries and/or suspected fractures are uncommon and easily treated on a backboard or with rigid immobilization. Thus, traction splints do not necessarily need to be applied by the rescue service [1]. Traction splints should not be applied to patients with multiple injuries in particular, since there are often contraindications to their use (pelvic/knee/leg/ankle injuries) [59]. Because of the existing contraindications for use of traction splints, particularly in critically injured patients, they are used only rarely. Traction splints are also contraindicated for use in displaced proximal femoral fractures [13].

Traction splints are useful and depending on the model, easy to apply for femoral fractures; thus, further studies are necessary. Traction splints reduce muscle spasms and thus, alleviate pain. Femoral shape is restored through traction and with the reduced volume there is a corresponding decrease in bleeding [14, 54, 55].

Photographs of wounds/open fractures can be taken for documentation (polaroid/digital). Photographic documentation of wounds, open fractures, or identified deformities appears useful, since this can avoid the need for re-exposure of wounds dressed or extremities immobilized in the pre-hospital setting until it is time for definitive treatment. Photographic documentation can help the subsequent treating physician in injury assessments. Photographic documentation may not extend the management/rescue time and must comply with privacy protection requirements [5, 41].

Severity and extent of injuries must be documented in the emergency physician protocol and the findings should be submitted to the subsequent treating surgeon, personally if possible [9].

Fractures

Key Recommendations:

1.60	**Recommendation**	**2011**
GoR B	**Grossly displaced fractures and dislocations should be approximately reduced in the pre-hospital setting if possible, particularly in cases of accompanying limb ischemia or longer rescue times.**	

Explanation:

The primary goal is to secure the local and peripheral circulation and to avoid secondary damage. Anatomic reduction is not the primary goal. More important is appropriate axial alignment and stable positioning with restoration of an adequate local and peripheral circulation [9, 11]. If there is no neurovascular compromise of the extremity distal to the injury, reduction can be foregone, in principle [5]. Grossly displaced fractures and dislocations should be approximately reduced to a more neutral position with axial traction and manual correction in the pre-hospital setting if possible, particularly in cases of accompanying limb ischemia or longer rescue times. It is important to perform assessments of peripheral perfusion as well as motor and sensory function (as possible) before and after reduction [9-11, 20, 41, 47]. Too much axial traction should be avoided, as this increases compartment pressures and decreases soft-tissue perfusion [9, 11].

Immediate attempts at reduction are called for when there are neurological or vascular deficits distal to the fracture. The same applies when the soft tissues or skin are compromised [41]. After successful immobilization, the peripheral perfusion, sensory and motor function should be re-checked [5, 41]. If neurovascular status worsens after a reduction attempt, the limb should be restored to the original position and stabilized as well as possible [41]. It is necessary to check whether reduced traction is necessary.

Reduction of ankle fracture/dislocations should only be performed by experienced providers. Otherwise, immobilization in the presenting position should be attempted [41]. In the case of common displaced ankle fractures with obvious deformity of the joint, the reduction should be performed at the accident scene. With adequate analgesia, controlled and continuous longitudinal traction with both hands on the calcaneus and dorsum of the foot can achieve an approximate reduction, which can then be immobilized. Neurovascular status of the limb should be documented again after the reduction.

Obvious fractures of a long bone shaft should also be treated in this manner. It is more difficult to estimate the full extent of fractures closer to the joints. Once the fracture is immobilized in a pain-free position, the patient should be transferred as quickly as possible to the hospital for further diagnostic studies [5, 60].

Excessive longitudinal traction should be avoided in distal femur fractures as this can compromise the popliteal vessels. The knee joint can be positioned in slight flexion (30-50 degrees) [10].

Open Fractures

Key Recommendations:

1.61	**Recommendation**	**2011**
GoR B	**Each open fracture should be cleaned of coarse contamination and given a sterile dressing.**	

Explanation:

Each open fracture should be identified and coarse contamination should be removed immediately [41]. Active bleeding should be controlled according to the following levels of intervention. Open fractures can be irrigated with normal saline solution [5, 41, 44, 51]. All open wounds should be covered with sterile dressings [9, 10, 20, 41, 51, 60]. Sterile dressings should be applied to open wounds without further measures for cleaning or disinfection. Coarse contamination should be removed [9-11]. Afterwards, they should be immobilized like closed injuries [51, 60]. Similar to closed fractures, it is important to give sufficient analgesia. The status of peripheral perfusion, sensory and motor functions should be documented immediately before and after application of an immobilization aid and should be checked regularly over the course of transport. When there is sufficient information and documentation from the rescue services, the dressings applied in the pre-hospital setting can be left in place until primary surgical treatment, with the goal of preventing further microbial contamination [41, 51].

Anti-microbial therapy should be initiated as soon as possible. Without antibiotic prophylaxis, the risk of infection rises markedly after five hours [51]. If available, intravenous antibiotics can be administered in the pre-hospital setting, normally with a 2nd generation cephalosporin with good bone penetration [10]. If the rescue time is prolonged, pre-hospital antibiotics should be given [44].

Key Recommendations:

1.62	**Recommendation**	**Modified 2016**
GoR A	**Active bleeding must be treated according to the following stepwise interventions:**	
	1. Manual compression	
	2. Compression dressing	
	3. Tourniquet	
1.63	**Recommendation**	**New 2016**
GoR 0	**If the foregoing measures are unsuccessful, hemostyptics can also be applied.**	

Explanation:

Measures to control bleeding must follow a stepwise approach. A primary attempt must be made to control active bleeding with manual compression and elevation of the extremity. Afterwards a pressure dressing must be placed. If this fails, a second pressure dressing must be placed over the initial dressing. A pack of bandages can be used as an aid to focused compression. If bleeding persists, an attempt must be made to apply pressure to an artery proximal to the injury. If possible, a tourniquet must be applied. For exceptional cases, the vessel can be clamped (cases of amputation, longer transport, neck vessels, anatomic positioning making tourniquet placement impossible) [9, 10, 20 41, 56].

Key Recommendations:

1.64	**Recommendation**	**Modified 2016**
GoR B	**•A tourniquet should be used immediately in cases of:**	
	•Life-threatening bleeding/multiple sources of extremity bleeding	
	•No access to the actual injury	
	•Multiple bleeding patients	

- **Profuse bleeding of the extremities with concomitant critical A, B, or C problems**
- **Lack of hemostasis using other measures**
- **Profuse bleeding of the extremity with time pressure from a dangerous environment**

Tourniquet

Use of a tourniquet requires appropriate analgesia [41]. Blood pressure cuffs can be applied with 250 mmHg to the upper arm and 400 mmHg to the thigh [9, 11]. The time of tourniquet application should be recorded [41, 42, 53]. The tourniquet must completely interrupt arterial blood flow. An incorrectly applied tourniquet can increase bleeding (when only the low-pressure system is compressed) [42]. Effectiveness should be assessed according to bleeding stoppage, and not by the disappearance of the distal pulse. In cases of fracture, bleeding can continue from the bone marrow [42].

If a tourniquet is ineffective, it should be re-applied with more pressure, and only after that, a second tourniquet should be considered, applied directly proximal to the first [42]. Cooling the extremity with an applied tourniquet can increase ischemia tolerance for longer rescue times [27].

There is insufficient evidence regarding the safe duration of tourniquet application. The general recommendation is 2 hours; however, this is based on evidence collected from normovolemic patients with pneumatic tourniquets [42]. If the transport time until operative treatment is less than one hour, the tourniquet can be left in place. For longer rescue times (> 1 hour), attempts should be made to release the tourniquet in a patient whose condition has stabilized. If bleeding is renewed, the newly applied tourniquet should remain in place until it is managed in the operating room [42]. After 30 minutes, the tourniquet should be checked to see whether it is still necessary. This is not indicated if the patient is in shock or if the attendant circumstances are adverse [21].

A retrospective case study of war casualties from the British military database found that of 1375 patients treated in English field hospitals over a particular time period, tourniquets were applied in 70 (5.1%). There were 107 tourniquets applied overall; 17 patients (24 %) had two or more tourniquets in place. Of these, five had double tourniquets applied for the same injury, and twelve had bilateral tourniquets (maximum number per patient: four, two on each lower extremity). 106 of the tourniquets were applied before reaching the field hospital. 61 of these 70 patients (87.1 %) survived. The mean ISS for survivors was 16, and for the mortalities (only six could undergo autopsy) was 50.

In the period of time before tourniquet use became standard (February 2003 to April 2006), only 9% of patients (6 %) were treated with tourniquets. In the following period (April 2006 to February 2007), 64 patients (91 %) received tourniquets. Without mentioning the total number of casualties in this period, the authors reported a 20-fold increase in tourniquet use. There were three complications directly caused by the tourniquets. There were two compartment syndromes (one each of the upper and lower leg, one after incorrect tourniquet application) as well as an ulnar nerve injury (without further details of follow up). Tourniquet application was assessed as life-saving in four cases of patients with isolated extremity injuries, hypovolemic shock and massive transfusion (including Factor VIIa administration) [15].

A retrospective study by Beekley et al., including 165 patients with traumatic amputation or severe vascular injury to an extremity, reported that pre-hospital application of tourniquets resulted in better bleeding control; this was particularly true in patients with multiple injuries (ISS > 15). Forty percent of soldiers (n = 67) received a tourniquet. There was no reduced mortality. The average tourniquet time was 70 minutes (minimum 5 minutes, maximum 210 minutes); there were no complications associated with use [12].

In a prospective cohort study of 232 patients with 428 applied tourniquets, Kragh et al. found no correlation between tourniquet time (average 1.3 hours) and morbidity (thromboses, number of fasciotomies, paresis, amputations). With tourniquet times over two hours there was a trend towards increased morbidity regarding amputations and fasciotomies.

A tourniquet should be applied as soon as possible. If the distal pulse is still present after tourniquet application, another tourniquet should be placed just proximal to the first to increase effectiveness. No materials should be used beneath the tourniquet, as these can lead to loosening. Tourniquets should be placed directly proximal to the wound. Tourniquets should be reevaluated for effectiveness over the course of treatment [36]. The use of tourniquets has been associated with higher survival probability. The use of tourniquets before the onset of shock has been associated with a higher survival probability, also when application occurs in the pre-hospital phase. Amputation was not required as a result of tourniquet use. The time of tourniquet application must be documented in the emergency medical record and must be reported during patient handover. In addition to the emergency medical record, the time of application can be written on the patient's skin with a waterproof marker just proximal to the tourniquet.

A study of 2838 U.S. military casualties in Baghdad with severe extremity injuries found that 232 patients (8.2 %) were treated with 428 tourniquets (on 309 injured extremities). Of these, 13 % died. Matched pair analysis including the parameters Abbreviated Injury Scale (AIS), Injury Severity Score (ISS), gender (all male), and age, of 13 casualties receiving tourniquets (survival rate 77 %, 10 of 13) and five patients (more were not identified during the time period in question) not receiving tourniquets (in whom there was indication for tourniquet application, and who all died in the pre-hospital phase, most after only 10-15 minutes!) found that early application of tourniquets significantly increased the survival probability in severe extremity injuries ($p < 0.0007$). In ten patients, the tourniquet was only applied after shock had manifested, and of these, nine died (90 %). The tourniquet was applied before the onset of shock in 222 patients, and only 22 of these died (10 %, $p < 0.0001$). 22 of the 194 patients receiving tourniquets during the pre-hospital phase (11 %), and 9 of 38 (24 %) receiving tourniquets first in the "emergency department," died ($p = 0.05$). Transient nerve paralysis occurred in ten cases without correlation to tourniquet time [37].

The use of tourniquets is an effective and simple (for medical and non-medical personnel) method to prevent exsanguination in the military pre-hospital setting [40]. The use of tourniquets is a safe, fast, and effective method to control bleeding from open extremity injuries and should be used routinely, and not only as a last resort (civilian study) [29]. Application of a tourniquet is considered a temporary measure to achieve rapid and effective hemostasis.

The goal should always be conversion of a tourniquet. This means that it should be replaced as soon as possible with other bleeding control measures. Given the short pre-hospital rescue times in civilian emergency services, conversion should only occur during the pre-hospital setting in exceptional cases (e.g. during long transport times during mountain rescues). More often the conversion should be delayed until early definitive surgical management occurs in the emergency department or in the operating room. Tourniquets can contribute to decreased mortality of war casualties and have low complication rates (nerve paralysis, compartment syndrome). The loss of an extremity because of tourniquet application is a rarity [23]. As with other emergency techniques, tourniquet application should not be performed for the first time during an actual rescue; rather, it should be learned under supervision and practiced with regular training.

Hemostyptics

In areas where tourniquets cannot be applied (proximal extremities), hemostyptic dressings can be used [23].

An analysis of autopsies for potential survivors of 982 soldiers from OIF (Operation Iraqi Freedom) and OEF (Operation Enduring Freedom) found that of the group of potential survivors (n = 232, 24 %), 85 % of the soldiers died of treatable hemorrhage.

In 13-33 % of cases, extremity bleeding was actually well or completely controlled; however, 20 % of cases had difficult-to-access axillary, cervical, or inguinal bleeding (junctional bleeding) [26, 30].

These numbers indicate the need to develop additional local hemostyptics/hemostatic devices.

According to Pusateri et al. [49], the following properties are desirable:

1. The product reliably stops strong arterial and venous bleeding within two minutes
2. No necessary and time-consuming preparations prior to product use
3. Simplicity of application, minimal training requirements
4. Lightweight and robust product performance
5. Durable, with a long shelf-life under extreme climatic conditions
6. No patient side effects
7. Biodegradable and resorbable
8. Inexpensive

As a result of this, a flood of new products has been developed in the past 15 years to prove themselves in various animal bleeding models, but to date, they have found only partial success.

In the course of the truly excessive testing of these products, the following experiences have crystallized.

1. Pressure to the site of bleeding is indispensable, regardless of the hemostyptic [43],
2. Not every product is suitable for every type of bleeding [24], and
3. To date, none has fulfilled all of the criteria.

The most common products can be divided into two groups based on hemostatic action.

1. Physically tissue-adherent and occluding the vessel injury (muco-adhesive)
2. The acceleration and amplification of intrinsic blood coagulation through two different mechanisms.
   - Fluid absorbing and thus, concentration of the pro-coagulant factors.
   - Activation of intrinsic coagulation and platelets.

The various most common local hemostyptics will be presented in the following and evaluated.

Chitin and Chitosan

The chitosan-based compress HemCon® (HemCon Medical Technologies Inc.®, Portland, OR, USA) can be called the "mother" of local hemostyptics for the treatment of bleeding in the pre-hospital setting.

Chitin and chitosan are polysaccharides in a group of biopolymers, and chitosan is derived from chitin.

In all likelihood, the hemostatic effect is based on induced vasoconstriction and rapid activation of erythrocytes, platelets, and coagulation factors. Chitosan also enhances platelet adhesion and aggregation along the damaged tissues [17].

The HemCon® compress was approved by the Food and Drug Administration/USA (FDA) for external hemostasis in 2002 with financial support of the U.S. Army. In 2003, the U.S. Army equipped its soldiers with this product, in contrast to the U.S. Marine Corps. In addition to the simple application and moderate cost of only 75 USD, storage under extreme conditions is also unproblematic.

The application option for narrow wound canals was improved with another FDA-approved chitosan dressing (ChitoFlex®, North American Rescue Inc.®, Greer, SC, USA) which, unlike the HemCon® dressing, can be shaped and inserted into a wound cavity.

The problem with these products is that effectiveness regarding survival is very inconsistent. Pusateri et al. reported that survival increased significantly in pigs with a grade V liver injury after HemCon® application [49]. However, the product showed varied levels of effectiveness following this, even within a single batch. This problem has also occurred with other chitin-based products (Rapid Deployment Hemostat®, Marine Polymer Technologies®, Danvers, MA, USA) [28, 50]. Even after a change to the manufacturing process, only one study showed satisfactory primary hemostasis for the product [31]. In further studies with arterial or arterial/venous bleeding, the product failed entirely [2, 22, 57] and has been removed from the armed services inventory over the past few years.

Celox® (MedTrade Products Ltd®, Cheshire, UK) is a chitosan-based powder. The mechanism of action is the formation of a gel-like plaque on the damaged tissue that remains there permanently. Hemostasis occurs as described above for chitosan. Like the products mentioned above, Celox® is not allergenic or exothermic. It is also in the same price realm as the other chitin products. In two studies, Celox® was more effective than Quikclot® and HemCon®. Both Kheirabadi et al. and Kozen et al. found decreased mortality and better primary hemostasis [32, 35].

The disadvantage is the powder form, which makes application to the wound base more difficult, particularly in cases of heavy bleeding. This was taken into account with a new form of delivery. Celox-D® (medical products, Portland, OR, USA) packages the powder into water soluble bags. However, this decreases the hemostatic effectiveness. A new injection system (Celox-A®, SAM medical products, Portland, OR, USA) appears promising. In a modified animal model that did not simulate a large wound, rather a typical gunshot canal (3 cm diameter) with complete transection of the femoral artery and vein, this product form achieved 100 % primary hemostasis as well as an 88 % survival rate [43]. Now there is also a dressing based on Celox® (Celox rapid Gauze®, MedTrade Celox-A Ltd®, Cheshire, UK) on the market. However, this dressing shows the positive results regarding rebleeding but not survival rate like Combat Gauze® [38].

Zeolite Group

In 2002, almost simultaneously with the HemCon® product, the Quikclot® product (Z-Medica®, Wallingford, CT, USA) entered the American market. It was approved by the FDA without clinical testing for moderate to severe external bleeding and introduced to the American armed forces, the U.S. Marine Corps, in 2003.

Quikclot® is based on a zeolite powder. It is a microporous, crystalline aluminosilicate of volcanic rock. It is distributed only as powder-filled pouches (Quikclot ACS +®).

Effectiveness is based on the extremely rapid withdrawal of fluid and concentration of the cellular blood components like platelets and clotting factors at the bleeding site in an exothermic reaction. In addition, the negative surface charge of the powder accelerates the coagulation cascade [3, 45].

The advantage of this product is the low price (approximately 20 USD) and the fact that it is not an allogenic or xenogenic preparation.

Because of the disadvantages regarding the temperature of the exothermic reaction (42–140.4 °C), Quikclot® was modified (Quikclot ACS +®). Nevertheless, increased temperatures still occur [7, 8, 48].

The study results for effectiveness are varied. On the one hand, in animal models with Grade V liver injuries and femoral artery and venous injuries, Quikclot® was associated with reduced blood loss as well as better survival compared to simple dressings [4, 48].

However, with pure femoral artery damage, studies were prematurely canceled due to decreased or no hemostasis [2, 32, 57].

There were also skin burns as well as nerve and tendon injuries [18]. Until its replacement with Combat Gauze®, however, it was used by official bodies according to the "life before wound" principle.

Kaolinite

Combat gauze® (Z-Medica®, Wallingford, CT, USA) is a dressing based on Kaolinite aluminum silicate. Kaolinite acts as an activator and accelerator of the intrinsic coagulation cascade. It has historic value in the control of clinical heparin therapy and for the treatment of diarrhea.

The prototype X-sponge, used as compress, showed a survival rate of 84% in a pig model [6]. Other animal studies achieved similar positive results with Combat Gauze® for arterial and arteriovenous bleeding [32, 34]. Even in an experimental set-up with animals with coagulopathy and acidosis, the kaolin-coated gauze was convincing [16]. There are no side effects except for mild endothelial swelling, and particularly none like those of WoundStat® (TraumaCure®, Bethesda, MD, USA, no longer on the market), known for embolization of hemostyptic components [33, 34].

It is stable for storage, inexpensive (approximately 25 USD) and easy to apply to the wound, even for narrow canals. However, the gauze is not biodegradable.

Since 2010, Combat Gauze® has been issued to various armed forces and in 2009 was introduced to the recommendations of the Committee on Tactical Combat Casualty Care.

Assessment

An assessment of the use of local hemostyptics is extremely difficult. Local hemostyptics fulfilling the criteria published by Pusateri et al. (see above) are not yet in existence. The hemostatic effectiveness of the products is difficult to compare with the different bleeding models/studies (arterial, venous, arterial/venous).

The study results are particularly sobering when simple, cheap, bandaging gauze achieves the same positive results as the hemostyptic to which it is compared [38, 43, 58]. These observations show all the more that the main focus of the treatment of penetrating, bleeding wounds must be on the trained packing of the gauze dressings or the hemostyptic and the application of pressure.

Amputations

Key Recommendations:

1.65	Recommendation	2011
GoR B	**Amputated parts should be coarsely cleaned and wrapped in sterile, damp compresses. They should be cooled indirectly during transport.**	

Explanation:

In addition to bleeding control, the amputation stump should be splinted and a sterile dressing applied. Only coarse contamination should be removed [9, 10]. The amputated part must be preserved. Bony parts or amputated digits should be taken from the accident scene or if necessary, brought afterwards.

The amputated part should be wrapped in damp compresses and cooled for transport, when possible using the "double bag" method. For this, the amputated part is placed in an inner plastic bag with sterile, damp compresses. This bag is then placed in another bag with ice water (1/3 ice cubes, 2/3 water), which is then sealed. This avoids secondary cold damage from direct tissue contact with ice or cool packs [5, 9, 10, 39]. The carrier used for transport should be marked with the patient's name as well as the time of cooling.

Amputations influence the choice of target hospital and advance warning should be given [5, 9].

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1.8 Genitourinary Tract

Key recommendations:

1.66	Recommendation	2011
GoR B	**When urethral injury is suspected, pre-hospital catheterization should be omitted.**	

Explanation:

In contrast to other injuries, injuries to the ureters, bladder, and urethra are not directly life-threatening [1, 2]. Kidney rupture is potentially life-threatening, but cannot be addressed directly in the pre-hospital setting except through volume replacement as an anti-shock measure. Thus, there are few specific pre-hospital measures for diagnosis and therapy of urologic injuries. Only transurethral catheterization of the bladder has been assumed to be valuable in this phase of care, since the presence and severity of hematuria can be important for the choice of target hospital as well as management on hospital arrival [3, 5]. Because loss of time especially during pre-hospital management is a relevant risk *quoad vitam* for multiply injured patients, pre-hospital catheterization may be advantageous in the pre-hospital setting when longer transport times are expected, providing it does not cause delay [4]. Insertion of a transurethral bladder catheter is a commonly accepted procedure internationally in pre-hospital treatment for polytrauma patients. There is a slight risk that the bladder catheterization itself can cause additional injury by transforming an incomplete urethral rupture into a complete rupture [3, 4]. In addition, the catheter can create a false passage in cases of complete urethral rupture [6-8]. Transurethral catheterization should thus be avoided in patients with clinical signs of urethral injury, until further diagnostic studies can be performed. Hematuria and blood at the urethral meatus are the leading clinical criteria suggesting urethral injury. In addition, dysuria, suspected pelvic fracture, local hematoma, and general mechanism of injury provide diagnostic clues [3].

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1.9 Transport and Target Hospital

Key recommendations:

1.67	Recommendation	Modified 2016
GoR B	**Air rescue operations should be used primarily for pre-hospital care of severely injured patients. Tactical considerations and the time factor should be taken into account.**	

Explanation:

For years, air rescue has been an important component of emergency services care not only in Germany but also internationally. In most European countries over the past few decades, a comprehensive network of air rescue bases has been constructed covering primary and secondary management sectors. To date, numerous studies have attempted to prove the effectiveness of air rescue. Potential causes for improved outcomes in multiply injured patients include shorter pre-hospital times (time of accident until hospital admission) as well as more aggressive pre-hospital management. Whether the use of air rescue services actually leads to decreased mortality, however, has remained controversial. Newer studies, some based on data from the DGU trauma registry database (*TraumaRegister DGU*®), seem to have found recognizable positive effects from air rescue, at least in Germany [2, 23]. More recent studies focus less on the value of air rescue itself, and more on, e.g., whether operations should be expanded to 24 hours.

Regarding pre-hospital management, up to 40% of polytrauma patients are treated by ground and air rescue teams together [48]. The importance of pre-hospital treatment time may need to be reevaluated. On the other hand, pre-hospital treatment time was also found to be approximately 16 minutes longer with air rescues than with ground rescue alone [2]. The reasons for this are primarily logistical aspects like the post-alarm of the air rescue service instead of immediate parallel alarm, such as can be seen e.g., in the BoLuS study (ground and air rescue interface, multi-centric cross-system interface analysis) from Hessen. The need for the sometimes enormous logistical costs for trauma centers was also examined. In addition to more complex technology, personnel resources in particular are necessary for optimal logistical support of multiply injured patients. To date, healthcare research has not yielded a clear evidence-based need for organization of trauma management within the DGU Trauma Network

(*TraumaNetzwerk DGU®*, TNW) and the trauma centers of that structure, but this is most likely because no structured data is available for comparison prior to the introduction of the TNW. One current study from Schweigkofler et al. reported improved survival for severely injured patients when treated with air rescue and hospital treatment [35, 36, 38, 39] in a national trauma center [50]. However, it was not clear how much of that was due to air rescue, and how much to management within the corresponding national trauma center.

The results regarding pre-hospital management of multiply injured patients by air rescue versus ground rescue services has been compared in many studies (evidence level 2B [2, 7 to 10, 12, 18, 28, 34, 45, 47, 48, 50, 59]). The primary endpoint for all cases was mortality. In most studies, the primary target hospital was exclusively a Level 1 Trauma Center [3]. In an analysis of air rescue missions for trauma in Germany (2005-2011), Schweigkofler et al. found that 85 % of patients were flown to a national trauma center, 14% to a regional trauma center, and only 1% to a local trauma center [50].

Eleven studies reported significantly reduced mortality (between -8.2 and -52 %) with air rescue.

For treatment of polytrauma patients, Schweigkofler et al. found a mortality of 13.6 % in the ground rescue emergency physician service group and 14.3 % in the air rescue group.

This represents an expected mortality (mean of RISC prognoses) of 15.6 % for ground rescue versus 18.0 % for air rescues. Thus, the standardized mortality rates for both groups are less than 1: ground rescue 0.874 and air rescue 0.793; this difference is significant ($p < 0.001$).

In the subgroup of polytrauma patients with severe TBI, there was improved survival for the 7 % of patients who were flown to a national trauma center. In a multivariate regression analysis for air rescue, Andruszkow et al. reported decreased mortality for cases flown to national trauma centers (OR 0.88; 95 CI 0.85–0.90) as well as to regional trauma centers (OR 0.86; 95 CI 0.83-0.91) [2].

A retrospective study (2007-2009) of patients with ISS > 15 treated in American Level I and II trauma centers found significantly improved survival for patients transported by air and significantly better quality of life after discharge from the corresponding acute care hospital.

On the other hand, six studies found no benefits for patients transported with air rescue, although they did show the following features.

Phillips et al. 1999 [39]: Mortality was the same in both groups, but the injury severity of the rescue helicopter (RTH) group was significantly higher ($p < 0.0001$); adjusted mortality comparison was not performed. Schiller et al. 1988 [45]: Patients in the RTH group had significantly higher mortality and injury severity, adjusted mortality comparison was not performed. Nicholl et al. 1995 [38]: Patients in both treatment groups were treated in Level II and III hospitals as well as in trauma centers. Cunningham et al. 1997 [18]: Patients in the RTH group with moderate injury severity (ISS = 21-30) had significantly reduced mortality; however, this result was not confirmed in the logistical regression. Bartolomeo et al. 2001 [19]: Only patients with severe head injuries were investigated (AIS $\geq$ 4). The ground-based emergency physician team performed invasive pre-hospital interventions relatively often so that the treatment level "gap" with the RTH group was minimal.

Comparability and Transferability of Study Results

As a result of the very different country-specific emergency rescue service structures, comparability of the studies must be debated. Particularly in the Anglo-American region, for example, there is a paramedic-based system, which cannot be compared structurally with the German emergency physician system. The patterns of injury also vary markedly among the studies. In Europe, trauma is predominantly blunt, while in the American region there is more penetrating trauma. The studies also vary significantly in terms of the transport route to be taken and the extent of pre-hospital management. The majority of studies have reported statistically significant decreases in the mortality of multiply injured patients, particularly those with moderate injury severity, with the use of air rescue. Other studies without evidence of direct treatment benefits, however, still show a trend for better results with RTH, since increased injury severity yields identical mortality rates.

In addition, all studies show a marked prolongation of pre-hospital treatment time. This is due in part to the longer transport distance, but also to a more comprehensive pre-hospital management strategy. Thus, Schweigkofler et al. found that an average 2.4 versus 1.8 of the 6 interventions documented by the DGU trauma registry database were carried out during air versus ground rescues. Invasive measures such as intubation and/or chest tube placement were more frequently implemented during air rescues. In summary, the present evidence finds a trend for decreased mortality of polytrauma patients with air rescue compared to ground-based rescue. This is especially true for patients with moderate injury severity, whose survival is very much dependent on the treatment received. This is likely due to better clinical diagnostic and management skills because of the increased training and experience of the RTH team. This conclusion is limited in its general validity and transferability because of the systematic failures of the cited studies, the heterogeneity of the regional emergency services and hospital structures, as well as types of injury.

Comparison Trauma Center versus Level II and III Hospitals

The importance of the duration of pre-hospital management for polytrauma patients has been intensively discussed and the term "golden hour" created. The goal must be to transport patients to hospitals with 24-hour acute diagnostic and treatment units, with rapid availability of all medical and surgical disciplines and of all corresponding acute care capacity. In addition, hospitals with increased numbers of critically injured patients had clearly better outcomes than those with fewer patients per year [66]. According to the DGU trauma registry database, the cut-off appears to be at a case number of 40 polytrauma patients per year.

Key recommendations:

1.68	Recommendation	Modified 2016
GoR B	**Severely injured patients should be primarily transported to an appropriate trauma center.**	

Explanation:

When analyzing the studies, hospital levels I-III but also sometimes I-IV are used. In this context, a Level 1 hospital equates to a maximum care facility, generally a trauma center, although the expression "Trauma Center" is not internationally consistent.

A Level 2 hospital equates to a specialty hospital, and Level 3 to a basic, general hospital.

With the development of the DGU trauma network, three new categories or trauma care have been defined [42, 55]: "national trauma center," "regional trauma center," and "local trauma center."

Each treatment level is clearly defined according to a certification process and there are obligations to maintain the qualification. In addition to previous structures, these facilities are linked via a "network." This enables resource sharing and integration of patient care, and it structures and simplifies transfers between hospitals. Because of the linking of the various care centers, the treatment of polytrauma patients is legitimized, according to the recommendations of the "White Paper" [54] by the German Trauma Society (DGU), even in local trauma centers.

The DGU's "White Paper" was produced in connection with the creation of the trauma network [54]. Among other things, it summarizes data from relevant international and national clinical studies, prospective data from the DGU trauma registry database, and data and critical analysis of the interdisciplinary S3 Guidelines for treatment of severely injured patients by the DGU, to give recommendations regarding structure, organization, and equipment for care of severely injured patients.

The authors of the White Paper recommend that severely injured patients be transported to the closest regional or national trauma center when there is a need for specialized trauma diagnosis/management in the emergency department based on mechanism of injury, pattern of injury, and vital parameters, and if it's within 30 minutes transport time. In cases where such a center cannot be reached within that time frame, the patient must be transported to an appropriate and if necessary local trauma center. From there, once the vital parameters have been stabilized and if there is reason to do so, the patient can be transported secondarily to a regional or national trauma center. This assignment must consider local and regional features of care as well as national treatment capacity, including the need for air rescue services, ideally regardless of the time of day.

Comparison of Level I Trauma Center vs. Level II/III Hospitals

The research yielded seven studies from the USA (n = 3), Canada (n = 2), Australia (n = 1), and Germany (n = 1) directly comparing outcomes from trauma centers (maximal care facilities) with Level II/III hospitals (specialty/general hospitals) [9, 16, 17, 31, 41, 43, 44].

All of these studies conclude that mortality decreases when primary treatment of blunt and penetrating trauma is performed in a trauma center. This has also been confirmed in current studies. Clement et al. (2013) compared outcomes of treatment in hospitals with higher versus lower case numbers for patients with TBI; there were significantly worse outcomes when fewer than six cases per year were treated [15]. Interestingly, hospitals treating more than 60 cases per year also showed somewhat worse outcomes than hospitals with moderate case numbers. Whether the explanation for this is increased injury severity in the large centers is unclear because of the study design.

Traumatic brain injury in conjunction with polytrauma has a worse prognosis when sent to an inappropriate center. Thus, once primary management is completed at the accident scene, these patients should be transported as soon as possible to a hospital with diagnostic and treatment capabilities for neurotrauma. Because of the considerable, not completely controllable sources of bias [20, 31] and the heterogeneity of the care systems investigated, this conclusion cannot be considered as definitive scientific evidence. Some authors have reported that stabilization in a regional hospital followed by transfer to a trauma center did not negatively impact mortality compared to patients brought there primarily [11, 27, 37, 40, 53, 55, 61]. Patients who died prior to possible transfer were not included in the studies. Thus, the "transfer" cohort has been positively selected. This needs to be considered in the final analysis. Concluding whether this treatment path is truly an equivalent alternative to direct admission to a trauma center or a clinic with comparable levels of care is thus impossible.

Even after implementation of the national trauma network, the potential positive effects of the network on outcomes cannot be clearly identified, especially because a before and after comparison is lacking. Only with the introduction of trauma network hospitals did the input of data from patients treated at certified centers become mandatory and available as a key source of data. An appropriate trauma center is defined by the resources offered, and also by the proven level of care within the framework of this external quality control. Logistical and especially regional conditions, however, must always be taken into account.

Key recommendations:

1.69	Recommendation	New 2016
GPP	**In cases of penetrating thoracic or abdominal trauma, the patient should be transported as quickly as possible to the nearest trauma center.**	

Explanation:
Penetrating trauma to the chest and/or abdomen requires a structured management approach. Depending on the severity of injury and/or on the thoracic/abdominal structures involved, exsanguination is a life-threatening consequence of trauma that can be treated only provisionally in the pre-hospital setting.

Although chest tube placement is an intervention that can be performed in the pre-hospital setting and that can adequately treat some 80-90 % of penetrating thorax trauma, there is currently no pre-hospital intervention that is considered to be definitive treatment [24, 30, 33, 65]. Thus, 10-20 % of all penetrating trauma to the chest and almost all penetrating trauma to the abdomen require diagnostic studies and treatment in hospital.

For pre-hospital management of the severely injured, a standardized and priority-oriented approach (e.g., according to the PHTLS algorithm) has prevailed that is time-sparing, effective, and safe for trauma patients [1, 25, 63].

In addition, several working groups have reported that after this pre-hospital care, critically injured patients benefit from rapid transport to an appropriate hospital and long-term outcomes improve [32, 44, 51, 56, 58, 67]. Particularly in cases of penetrating trauma to the chest and/or abdomen, the minimization of pre-hospital time is considered essential to allow life-saving hemostasis via surgery or other interventions that can only be carried out in a hospital [32, 51, 58].

In Germany, in view of the shorter reaction times between alert and arrival of the rescue service at the accident site, there is no significant potential for time-related optimization. According to the work of several research groups, the shortest possible on-scene time seems to improve survival probability in cases of penetrating trauma and when there is no chance for pre-hospital measures to prevent exsanguination [13, 14, 26, 52, 58].

Spaite et al. documented an average on-scene time of 8.1 minutes in a U.S. American urban setting (Tucson). McCoy et al. reported 13 minutes in cases of blunt trauma and 11 minutes for penetrating trauma in Orange County, CA, and Ball et al. found an average on-scene time of 12 minutes in Atlanta, GA [5, 32, 57].

The short on-scene times are not directly due to the “scoop and run” approach (Basic Life Support, BLS). Eckstein at al. found that the implementation of ALS measures, such as intubation, does not necessarily prolong on-scene time (average 12.8 minutes) [21].

Similar results with times under ten minutes “on-scene” in cases of penetrating trauma and an Advanced Life Support (ALS) approach were evident in a 2011 study by Funder et al. of 467 patients in a European, urban setting (here: Copenhagen). Thus, in this patient group with penetrating trauma, increased mortality was found with on-scene times over 20 minutes. Similarly, more frequent implementation of invasive measures in the pre-hospital setting was associated with a significantly higher mortality [22].

A single-center study by Ball et al. found that reductions in pre-hospital on-scene times and transport times in an urban setting increased overall in-hospital mortality. However, the authors did not conclude that this outcome resulted from minimal pre-hospital treatment. The reduction in pre-hospital time enabled 34% more patients to reach the hospital alive compared to the control group. These patients were also frequently hemodynamically unstable. The authors concluded that despite increased overall mortality, the only chance to positively affect outcomes in patients with bleeding penetrating abdominal and chest trauma is surgical hemostasis. They also found that certain injuries are severe enough to appear un-survivable despite this measure; however, this severity cannot be clearly evaluated in the pre-hospital setting [5].

Band et al. reached a similar conclusion [6]. They compared pre-hospital transport of patients with penetrating trauma by the police versus the Emergency Medical Service (EMS) in a U.S. American urban setting (here: Philadelphia). In their group of 2127 patients, they found that the overall mortality in patients transported by the police was higher, but that mortality adjusted according to injury severity (TRISS) did not differ.

In a cohort of 91 132 patients, Johnson et al. even found a survival advantage (TRISS adjusted) for patients with penetrating trauma transported privately (9.6 %) [26]. They also attribute this to reduced pre-hospital time and fewer pre-hospital interventions, but also do not exclude other confounders, e.g. urban versus rural environment, pre-trauma health status, or unrecorded pre-hospital mortalities.

Based on these results, prompt surgical (and/or interventional) hemostasis in hemodynamically unstable patients with penetrating trauma to the chest and/or abdomen is the only therapy that has guaranteed benefits. Correspondingly, for patients with penetrating chest and/or abdominal trauma, the most rapid transport possible to the closest trauma center or hospital equipped to perform immediate surgical hemostasis is recommended to guarantee the fastest possible diagnostic and therapeutic measures.

Key recommendations:

1.70	**Recommendation**	**New 2016**
GPP	**To avoid transition problems during registration and/or transfer of severely injured patients, appropriate and standardized communication methods must be used.**	

Explanation:

In order to guarantee a smooth treatment course for severely injured patients, and thus, also meet time-associated demands, for example according to the 2008 Key Points Paper on Emergency Medical Management of Patients in Hospital and Pre-Hospital, **it is necessary to establish appropriate documentation procedures using resources available (e.g. IVENA [49]) and communication methods (e.g. establishment of a trauma mobile phone, Rescuetrack^{TM}, MANDAT) [29, 62, 64].**

During hand-over in the emergency department, appropriate interdisciplinary and inter-professional training methods for the emergency physicians, the paramedical staff, and the corresponding hospital personnel ensure standardized transfers according to the ABCDE scheme. The use of checklists for registration and transfers can also reduce mistakes at the intersection of pre-hospital and hospital care [4, 46].

Benefits for teamwork, technical competence, system checks, and a culture of safety among other things are evident in the areas of polytrauma and emergency department care. However, scientific proof of the positive effects of such interventions regarding increased survival of affected patients is not available [60].

Conclusion

The studies comparing air with ground rescue reveal a trend towards decreased mortality with the use of air rescue. If available, primary air rescue should be used for pre-hospital management of severely injured patients, because survival improves as a result, especially for moderate to high injury severity. Logistical aspects and the time-factor should be considered. Severely injured patients should be primarily transported to an appropriate trauma center, since this approach decreases mortality. If a regional or national trauma center is not reachable within a reasonable time-frame (recommendation according to the White Paper: 30 minutes), a closer hospital capable of implementing primary stabilization as well as life-saving emergency surgery should be selected for transport. If transfer to a regional or national trauma center is necessary, the patient can be transferred secondarily when hemodynamically stable and when other specific criteria are met.

In cases of penetrating thoracic or abdominal trauma, the patient should be transported as quickly as possible to the nearest trauma center. Prompt surgical (and/or interventional) hemostasis in this type of hemodynamically unstable patients is the only therapy that has guaranteed benefits.

To reduce errors as well as information gaps, a structured and thus, standardized handover process should be performed. Corresponding education and training should thus be carried out in an interdisciplinary and inter-professional setting.

The evidence table for this chapter is found on page 135 of the guideline report.

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1.10 Mass Casualty Incident (MCI))

A mass casualty incident must be differentiated from a disaster. Strategies for coping with a mass casualty incident can be transferred to a disaster scenario only to a limited extent.

One particular type of mass casualty incident is a terrorist attack, which distinguishes itself from other events strategically/tactically and according to required medical treatment based on the patterns of injury, the time-related development (multiple attacks at various times), and the chance of a continuing threat also to rescue personnel.

Strategies for dealing with a mass casualty incident should therefore include penetrating injuries from automatic firearms and specific injuries from improvised explosive devices that can be present during terrorist attacks, in addition to "classic" patterns of injury. These multidimensional injuries represent a particular qualitative medical challenge, since there is limited expertise in Germany.

A mass incident of severely injured presents an extreme challenge for emergency rescue personnel at the site as well as in the receiving hospitals. The human and material resources standing by must be allocated based on triage for the most efficient individual treatment possible. However, it must be clear to all parties that it may be necessary to abandon individual-based medicine for a certain time to ensure survival of the greatest number of patients. This conversion is a special challenge and also a burden for the entire staff, and requires particular attention.

As a rule, triage performed by physicians or non-physician staff is complicated by the fact that the severely injured patients must be rapidly and reliably identified among a large number of patients with minor injuries. In general, there is less of a problem with "under-triage," i.e., not recognizing the critically injured, than with "over-triage," in which non-critical injuries are overestimated. The rate of over-triage correlates directly with mortality of critically injured patients [4], since in this case, limited prehospital and hospital resources that are urgently needed for the critically injured will be expended inappropriately.

In 2008, Jenkins et al. analyzed various established Anglo-American triage systems and found that no algorithm was superior to the others, considering the evidence available at the time. Therefore, the authors concluded that there was a need to develop a universally workable algorithm [8].

In 2011, representatives of U.S. medical societies/organizations approved the SALT triage concept (Sort, Assess, Lifesaving Interventions, Treatment/Transport) that had been presented by Lerner et al. in 2008 [11–13].

In 2015, Streckbein et al. evaluated twelve international and national triage systems using an evidence-based literature review [18]. The authors concluded that none of the systems was superior to the others according to scientific data, and that none of the various concepts is well-established in Germany.

Because of higher priority assignments of other key recommendations, an improved version of the previous triage algorithm, which was based on a previous consensus because of insufficient evidence, could not be approved in this current version of the S3 Guidelines.

The basis for the current triage system was the STaRT algorithm (Simple Triage and Rapid Treatment) used in North America, which enables targeted sorting of injured patients immediately by the first-responding emergency personnel. The STaRT concept was originally developed for California Fire Departments [2]. In addition to priorities of the ATLS® and PHTLS guidelines [1, 15], the algorithm for pre-hospital triage considers specific requirements of the German emergency physician service [16] in terms of both the duties and the functions of the Chief Emergency Physician or the Health Care Administration, as well as the corresponding triage categories.

Patients in an acutely life-threatening condition of triage category I/red are identified according to ABCD priority (Airway, Breathing, Circulation, Disability) and treated as quickly as possible. When an acute surgical indication is present, such as thoracotomy/laparotomy to control bleeding or decompression for traumatic brain injury, the patient is released after a second screening by the Chief Physician for immediate transport to the nearest appropriate hospital. After the start of triage, all injured patients who are able to walk are initially assigned to triage category III/green and are referred to the meeting area for slightly injured. This approach particularly considers the problem that among the large number of patients, only a small proportion have acutely life-threatening injuries and require immediate treatment. In addition to life-saving interventions that can be carried out at the scene, this also includes rapid, resource-dependent transport for acute surgical care.

National developments of the STaRT algorithm and the previous triage algorithm are published in the mSTaRT algorithm from 2006, which defines additional types and extent of emergency treatment, the time point and consequences of the second triage regarding the urgency of emergency transport, as well as critical findings for the detection of patients in triage category II/yellow [9].

The mSTaRT Trauma and Intox, introduced in 2013, includes detection of potential toxic agents and the corresponding procedures necessary such as decontamination for each patient category [6]. In addition, critical findings have been incorporated regarding subsequent triage in terms of traumatic brain injury, inhalation injury with stridor, and possible intoxication.

For military or police situations, Ladehof et al. introduced the tacSTaRT in 2012. The tacSTaRT modifies the early reaction to critical bleeding prior to triage and supplements with further explanations [10]. This approach is particularly relevant because, as seen in the "Resuscitation" chapter, life-saving emergency measures such as hemostasis with tourniquets and decompression of tension pneumothorax, etc., must be performed as soon as possible in acute life-threatening situations.

Future national triage algorithms based on STaRT and/or ATLS/PHTLS should accordingly prioritize these aspects of life-saving interventions, e.g. hemostasis with tourniquets, decompression for tension pneumothorax, freeing the airway (including 2x ventilation in children), as well as antidote administration, to occur prior to triage. First responders should therefore have the required equipment as well as training in these interventions.

In 2014, the German Society of Disaster Medicine (*Deutschen Gesellschaft für Katastrophenmedizin*, DGKM) and the Federal Office for Civil Protection and Disaster Relief (*Bundesamt für Bevölkerungsschutz und Katastrophenhilfe*, BBK) proposed a universal triage system for surgical and medical-conservative clinical pictures [3]. PRIOR (Primary Ranking for Initial Orientation in Rescue service), based partially on the established ABCDE algorithm, references conditions instead of physiological parameters, and is not completely compatible with mSTaRT and tacSTaRT.

The use of triage systems should be included in local considerations, which along with medical treatment basics must coordinate emergency medical services with cooperating services (e.g., fire department, police, THW, disaster protection, military) [17]. Triage algorithms are adapted to local considerations if necessary and should also be adjusted to existing disaster contingency plans or similar.
One thing remains unaffected: appropriate preparation [5] is the best prerequisite to confront this type of situation, regardless of contingencies [7, 14]. This means consistent processing and improvement of structure and process quality of all participating bodies at the scene. In addition to the analysis of previous disasters, simulation is an appropriate method for evaluation and further development.

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2 Emergency Department

2.1 Introduction

Because of the complexity of the individual processes, the management of severe and/or multiply injured patients in the Emergency Department presents a great challenge to the treatment team. Treatment in the emergency department should thus be definitively characterized by predefined procedures and a common language. Here, the pre-hospital, emergency department, and primary operative management phases meet. Course concepts such as Pre-Hospital Trauma Life Support® (PHTLS®) for pre-hospital treatment and Advanced Trauma Life Support® (ATLS®) or European Trauma Course® (ETC®) for in-hospital treatment can be used to automate and improve this process using a clear hierarchy of treatment levels and a common language [9, 12]. Trauma care in the emergency department is very relevant regarding survival probability of severely injured patients. Mathematical models show that about two thirds of the explainable variance of a model including the patient-dependent factors of the pre-hospital and emergency department phase are accounted for in the emergency department phase [8].

The establishment of defined standard operating procedures (SOPs) and the accompanying validation through the DGU trauma registry (*TraumaRegister DGU*®) have led to verified improvements in survival probability and quality of care after severe trauma [4, 5, 9, 10, 12]. In addition, there are numerous indications that the establishment of treatment recommendations as outlined in the first version of the *S3 Guidelines on Treatment of Patients with Severe and Multiple Injuries* in the clinical SOPs can lead to improvement in patient outcomes [11]. This also applies to increased frequency of multilayer spiral computer tomography (MSCT) in the early phase of emergency department trauma care, which enables a rapid, highly precise diagnostic study also for unstable patients [6, 7]. It is important that each hospital has a trauma algorithm developed by interdisciplinary consensus, and that all potential participants are familiar with it.

As with all complex medical process, errors can occur. In this case, not every error must adversely affect treatment quality [10]. However, an accumulation of errors can have fatal consequences for the patient. Thus, unemotional review and processing of complications is the basis for sensible quality management and should be permanently established within the quality circle of hospitals treating severely injured patients [5].

In many hospitals, task forces and quality circles have been successfully initiated, which regularly evaluate and improve their own trauma protocols using actual cases. The management of such quality circles, like responsibility within the trauma bay, remains a point of debate among specialty societies. Since the diagnosis and treatment of severe trauma is a core component of trauma surgery, physicians of this specialty could be candidates to run both quality circles and trauma care within the emergency department [5]. However, it can't be forgotten that there are other functional treatment concepts for emergency department trauma care [1,3,13]. In the guideline, this sensitive territory is addressed in various places, since treatment concepts focused on pure multidisciplinary teamwork without a team leader can also be viable. In such cases, however, there should be a clear delineation of responsibility for various situations in advance, particularly in preparation for forensic issues [2].

This “Emergency Department” section has been completely revised and updated with the latest available evidence during the re-issue of the *S3 Guideline on Treatment of Patients with Severe and Multiple Injuries*. At the repeated requests of specialist societies, a section dealing with radiological diagnostic studies and imaging, and the best use of these, was completely redone. Thus, the Emergency Department section now includes its own chapter on “Imaging in the context of severely injured care in adults and children.”

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2.2 Emergency Department—Staffing and Equipment

For the care of polytrauma patients, there are over 600 trauma centers available in Germany. With the organization of these trauma centers into more than 50 trauma networks, almost comprehensive certification of the entire nation has been achieved.

The auditing processes required to pass through national, regional, and local trauma centers have enabled implementation of a higher degree of standardization throughout regarding personnel, structural conditions, and/or professional competence for the treatment of multiply injured patients.

To date, no investigations have yielded evidence that the implementation of trauma networks significantly reduces mortality for severely injured patients. However, Ruchholtz et al. found that triage required to distinguish mild and severe injuries works very well already. Among other things, the authors found that patients with severe injuries and relevant vital function disturbances (GCS, hypotension) were treated more often in national trauma centers than in regional and local trauma centers. Similarly, the authors found that the secondary (additional) transfer rate to national trauma centers, with 13.4 %, was significantly higher than rates to regional or local trauma centers (4.6 % and 2.3 %).

The Trauma Team

Key recommendations:

2.1	Recommendation	2011
GoR A	**For the care of polytrauma patients, a specific team (the “Trauma Team”) must work according to an organized plan and/or have completed special training.**	

Explanation:
To achieve coordinated, balanced cooperation among various staff when managing polytrauma patients, it is commonplace over the world to assemble fixed teams for trauma care within the emergency department, which work according to pre-structured protocols and/or have completed special training (particularly ATLS®, ETC, Definitive Surgical Trauma Care [DSTC™]) [4, 33, 50, 52, 54, 59]. Various studies have found clinical benefits for this trauma team concept [13, 31, 41, 57]. For example, Ruchholtz et al. found that an interdisciplinary team, integrated into a quality management (QM) system and acting on the basis of internal hospital guidelines and discussions, works very efficiently under joint surgical and anesthesia management [8, 58].

Key recommendations:

2.2	Recommendation	2011
GoR A	**The basic trauma team must consist of at least 3 physicians (2 surgeons, 1 anesthesiologist), of whom at**	

least one anesthesiologist and one surgeon must have attending status.

Explanation:
There are no validated studies on the composition of the emergency department trauma team; thus, statements regarding team composition can be based only on how these are predominantly assembled worldwide. The question as to which specialties should be primarily represented in the emergency department trauma team often depends on local conditions [6, 9, 11, 12, 14, 21-26, 28, 32, 34, 35, 40, 43, 48, 53]. Some studies from abroad have reported that the majority of polytrauma patients can be effectively managed with only two physicians [3, 7, 12]. Depending on the pattern/severity of injury, however, the initial team of at least 2-3 people can then be supplemented with additional colleagues [30, 42, 49]. Review of the international literature indicates that almost all teams consist of either specialized trauma surgeons with varying levels of experience or general surgeons with (long-term) experience in trauma management, also with different levels of training.

The above constellation of at least three physicians can serve only as a minimum number, and should be enlarged as needed with 1-2 other physicians (e.g. radiologist, neurosurgeon) according to the size and treatment level of the hospital as well as patient numbers. In any case, management of severely injured patients must be carried out by a qualified surgeon. Minimal qualifications must be the level of specialist in either Orthopedics and Trauma Surgery or General Surgery according to the regional medical association (*Landesärztekammer*, LÄK), Rules for Specialist Training for Physicians, as at 07/2009. The treating anesthesiologist must also have a minimum qualification of specialist.

In addition to the required medical competence of the emergency department trauma team, medical/anesthesia/technical support personnel are of course indispensable. Regarding support personnel, the DGU White Paper (2nd Edition, 2012) calls for two surgical, one anesthesia, and one medical/technical/radiology (MRTA) nurse/technician(s) per individual care level.

The function and necessity for a "trauma leader" in the Emergency Department is debated in the literature. Even in the consensus conferences while developing the S3 guideline, the need for a "team leader," his/her duties, and assignment to a particular specialty were debated intensely. A structured literature review of these topics was performed during the guideline development process. In terms of patient survival, there was no credible evidence for the superiority of one particular management structure in the emergency room ("trauma leader" versus "interdisciplinary management group"), or for the assignment of a "trauma leader" to one particular specialist area (trauma surgery, surgery versus anesthesia).

Hoff et al. [21] found that bringing in a team leader ("command physician") improved the care and treatment sequences [22]. Alberts et al. also found evidence of improved treatment sequences and outcomes after introduction of the "trauma leader" strategy [1]. Because of the many tasks, including patient handover, patient examination, implementation and monitoring of therapeutic and diagnostic measures, consultation with other specialist disciplines, coordination of all medical and technical team members, preparation for examinations to follow emergency room care, communication with relatives after completion, etc., that the "trauma leader," in principle, must oversee, this job and these duties must be performed either on an interdisciplinary basis or by a "team leader" experienced in the management of multiply injured patients. In interdisciplinary processes, it is even more important to ensure that treatment sequences are agreed to and consensual, to avoid any time delays [19, 22, 39, 53].

According to recommendations of the American College of Surgeons Committee on Trauma (ACS COT), a qualified surgeon must assume team leadership [8, 58]. A large comparative study of over 1000 patients found almost equal mortality and admission stays regardless of whether one of four trauma surgery specialists or one of twelve general surgeons were responsible for trauma care in the emergency department, although the general surgeons had trauma surgery experience [43]. Khetarpal reported shorter management times and time to surgery when "Trauma Surgeons" versus "Emergency Physicians" acted as leader, but this had no apparent effect on treatment outcomes [8, 58]. Sugrue et al. confirmed that there is no critical difference regarding who leads the trauma team, as long as the leader has sufficient experience, expertise, and training [8, 58]. Anesthesia leadership of the trauma team has also been practiced effectively, cooperatively, and successfully in many sites for years.

Interdisciplinary leadership models consider increased specialization of the individual disciplines in particular. Each specialty has predefined tasks and is responsible for those tasks at defined time points during the emergency department phase of care. The leadership group, comprised of anesthesiology, surgery, radiology, and trauma surgery (in alphabetical order), thus confers at strictly defined time points and also, when the situation calls for it [60].

Nevertheless, experts are in favor of clear delineation of responsibilities based on local conditions, agreements, and skills. Team leadership should be encouraged, regardless of specialty or whether coming from an individual or a group. The duties of team leadership are to collect and inquire about the findings from the individual specialty team members and to make consequent decisions. Team leadership leads communication and, with team agreement, establishes the next diagnostic and therapeutic steps. The functions and qualifications of the "Team Leader" or the "Interdisciplinary Leadership Group" should be established within the facility quality circle for the Emergency Department. Ideally, after agreement, the "best" candidate or candidates should be given the tasks of "Trauma Leader" or "Interdisciplinary Leadership Group." Rules must be made in particular for the following points, which must stand up to a "best practice jurisdiction":

- Responsibility,
- Leadership structure for coordination, communication, and decision-making within the context of trauma care in the Emergency Department,
- Monitoring and quality assurance (implementation of quality circles; identification of quality and patient safety indicators; continuous review of structure, processes, and outcomes).

In addition to technical skills, non-technical skills (NTS) play an important role in trauma team work. The most important NTSs are

- Decision-making,
- Situational awareness,
- Teamwork,
- Task distribution,
- Communication.

Training for NTSs should be carried out regularly in an interdisciplinary and inter-professional manner.

For organizational reasons, a multiply injured patient is generally assigned to the Emergency Department to which the Trauma Leader belongs. To enable optimal management of the post-acute phase, it is recommended that all involved specialties complete reevaluation of the injury pattern within 24 hours. At this time, the discipline to take primary responsibility for each polytrauma patient must be defined, with consensus of all participants. This ensures that the patient is appropriately assigned for further treatment according to the main injury.

Key recommendation:

2.3	Recommendation	2011
GoR A	**Trauma centers must keep expanded trauma teams.**	

Explanation:
The size and composition of the expanded emergency department team is determined by the care level of the respective hospital and the corresponding expected level of injury severity, as well as by the maximum number of surgical interventions that can be performed on site if necessary (*White Paper*). National trauma centers, having the highest care levels, should thus involve principally all specialties performing emergency care. An overview of this is given in Table 11. A qualified specialist (attending) from a consulted department should be present within 20-30 minutes (see below).

Key recommendation:

2.4	Recommendation	2011
GoR A	**Attending physicians needed for subsequent care must arrive within 20-30 minutes of being alerted.**	

Explanation:
A comparative hospital study found that it was not absolutely necessary for the trauma surgeon to be available in-house at all hours, provided the distance to the hospital was not greater than 15 minutes and a resident was already in the hospital [11]. Allen et al. and Helling et al. report a limit of 20 minutes [3, 20]. In contrast, Luchette et al. and Cornwell et al. found "in-house" readiness to be an advantage [9, 35], although Luchette showed that only diagnosis and start of surgery were more rapid when an attending physician was initially present; both the duration of intensive care and mortality for patients with severe thoraco-abdominal or head injuries were unaffected [13, 31, 41, 57].

In a comparison over several years, calculations from the English Trauma Audit and Research Network (TARN) indicated significantly reduced mortality (60 % vs. 32 %) with increased presence of a qualified specialist/attending physician [29]. Wyatt et al. also reported that severely injured patients in Scotland (n = 1427; ISS > 15) were treated more rapidly and were more likely to survive when they were treated by an experienced specialist/department chief than by a resident physician [61]. In the ACS COT recommendations, the presence of an attending surgeon for management of severely injured patients is not mandatory, provided a senior surgical resident is directly involved [8, 58]. In a retrospective analysis over a period of 10 years, Helling et al. found no relevant improvement in treatment outcomes when the attending physician was present from the outset [37, 41, 55]. For patients with penetrating injuries, in shock, with a GCS < 9 or ISS ≥ 26, there was no difference in care quality with regard to mortality, start of surgery, complications, or intensive care unit stay duration when the on-duty physician participated in subsequent care within 20 minutes ("on call"). Only the initial care period and the total hospital stay were decreased for blunt trauma patients when the attending physician was in the emergency room ("in-house") from the outset. These outcomes have been largely confirmed by Porter et al., Demarest et al., as well as Fulda et al. [11, 17, 45].

Overall, it can be concluded from these results that an attending physician does not need to be present at the outset of emergency room trauma care when a surgeon qualified in the care of the severely injured (specialist grade and if applicable, ATLS® and ETC certified) carries out the initial management steps. However, rapid accessibility of the attending physician should be ensured.

A thoracic surgeon, ophthalmologist, oral and maxillofacial surgeon (OMFS), and otorhinolaryngologist (ENT) should be reachable within 20 minutes [19, 28, 36, 44]. According to Albrink et al. [2], the thoracic surgeon should be consulted as soon as possible, particularly in cases of aortic lesions.

According to the literature, the presence of a pediatric surgeon is not mandatory for the basic trauma team. The studies of Knudson et al., Fortune et al., Nakayama et al., Rhodes et al., Bensard et al., D'Amelio et al., Stauffer and Hall et al. found no evidence for improved treatment outcomes with the involvement of specialized pediatric surgeons [5, 10, 16, 18, 27, 38, 46, 51]. However, in cases of pediatric trauma at a hospital with a pediatric surgery facility, pediatric surgical/trauma experts should be involved in care. Details should be clarified in the local quality circles.

An anesthesiologist, required for continuing care of the multiply injured patient, must also present within 20–30 minutes of being alerted.

Key recommendation:

2.5	Recommendation	2011
GoR B	**The treatment area within the emergency department should allow 25-50 m2 per patient.**	

Explanation:
The information provided is based on a) recommendations for primary management of the patient with traumatic brain injury in polytrauma by the individual working groups and circles of the German Society of Anesthesiology and Intensive Care Medicine (DGAI), the German Society for Neurosurgery (DGNC), and the German Interdisciplinary Association of Intensive Care and Emergency Medicine (DIVI). Minimum size of 25 m^2 is recommended per treatment area [56].

Room size can also be calculated b) using the specifications of the Technical Rules for Workplaces (*Arbeitsstätten-Richtlinie*, ASR), the Workplaces Ordinance (*Arbeitsstättenverordnung*, ArbStättV, 2nd section; room dimensions, air space), the German X-ray Ordinance (*Röntgenverordnung*, RöV), and the Technical Rules for Hazardous Substances (*Technische Regeln für Gefahrenstoffe*, TRGS). It specifies that 18 m^3 of breathable air per person carrying out heavy physical activity, and 15 m^3 for average physical activity, must be ensured in rooms with natural ventilation or air conditioning; 10 m^3 is estimated for each additional person who is there temporarily. Thus, a room volume of about 75-135 m^3 would be required for 5-9 persons (3-5 physicians, 1 medical radiology technician, 1-2 trauma surgery and/or anesthesia nurses), and an assumption of average physical work (lead aprons worn during care). With a ceiling height of 3.2 m, this corresponds to a room size of approximately 23-42 m^2. Not included in the calculation is the loss of space through anesthesia and ultrasound equipment, work surfaces, patient stretcher, cupboards, etc., so that a total of 25-50 m^2 per unit should be the starting point. If it is possible to treat a maximum of 2 severely injured patients simultaneously, the area is enlarged accordingly. Section 38 (2) of the German Workplaces Ordinance of 1986 specifies a clear door width of at least 1.2 m with a door height of 2 m for paramedic and first aid rooms.

Key recommendation:

2.6	Recommendation	2011
GoR B	**The treatment area, the ambulance entrance, the Radiology department, and the operating rooms should be located in the same building. The heliport should be located on the hospital grounds.**	

Explanation:
All screening tests necessary for emergency surgery (laparotomy, thoracotomy, external fixator/pelvic C-clamp) must be kept in readiness.

Table 11: Composition and presence of specialist level physicians in the expanded emergency department trauma team in relation to hospital care level

Specialty/Department	National TC	Regional TC	Local TC
Trauma Surgery	X	X	X
General or Visceral Surgery	X	X	X
Anesthesia	X	X	X
Radiology	X	X	X
Vascular Surgery	X	C	–
Neurosurgery	X	C	–
Cardiac or Thoracic Surgery	*	*	–
Plastic Surgery	*	*	–
Ophthalmology	*	*	–
ENT	*	*	–
OMFS	*	*	–
Pediatrics or Pediatric Surgery	*	*	–
Gynecology	*	*	–
Urology	*	*	–

X: Required
C: Cooperation agreement**
*: Optional
–: Not required

**C: Cooperation agreement

Treatment of vascular and/or neurosurgical injuries require "cooperation agreements" in regional trauma centers. This rule - if no vascular surgeon and/or neurosurgeon is available in-house, cooperation with a nearby department/hospital for vascular and/or neurosurgery (e.g., provision of a consultant, transfer of the patient, surgical readiness, etc.) can be agreed upon. 24 hours of acute care must be ensured 365 days per year.

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2.3 Emergency Department Trauma Team Activation

Efficient trauma score systems or parameters should select and/or identify patients precisely enough that the necessary treatment is allotted to each patient according to injury severity. The difficulty lies in adequate injury assessment. Ideally, trauma team activation criteria should minimize the rates of both undertriage and overtriage of severely injured patients. While undertriage carries a risk to patient safety, overtriage is associated with considerable costs as well as disruptions to clinical routine. Thus, the effectiveness of individual triage parameters leading to activation of the emergency department trauma team should be evaluated using measures such as sensitivity, specificity, positive predictive value, and the calculation of overtriage and undertriage rates. The American College of Surgeons Committee on Trauma (ACS COT) [1] considers an undertriage rate of 5 % with simultaneous overtriage rate of 25-30 % necessary for efficient trauma care in the emergency department. Kane et al. concluded that the rate of overtriage could not be brought under 70 % while achieving a sensitivity greater than 80 %.

Activation Criteria

Key recommendation:

2.7	Recommendation	Modified 2016
GoR A	**The Emergency Department Trauma Team must be mobilized for the following injuries:**	
	•Systolic blood pressure below 90 mmHg (age adapted for children) after trauma	
	•Penetrating injuries of the torso/neck area	
	•Gunshot wounds to the torso/neck region	
	•GCS below 9 after trauma	
	•Respiratory impairment/need for intubation after trauma	
	•Fractures of more than two proximal long bones	
	•Flail Chest	
	•Pelvic Fractures	
	•Amputation injury proximal to the hands/feet	
	•Spinal cord injury	
	•Open head injury	
	•Burns > 20% and grade ≥ 2b	

Explanation:

Blood pressure/Respiratory rate

Individual studies have reported that hypotension with a systolic blood pressure below 90 mmHg after trauma is a good predictor/good criterion to activate the emergency department trauma team. Franklin et al. [6] found that 50 % of trauma patients with hypotension in the pre-hospital phase or on hospital arrival were sent for immediate surgery or transferred to the intensive care unit. Overall, 75 % of hypotensive patients underwent surgery during hospital admission.

Tinkoff et al. [22] reported 24-fold increased mortality, as well as 7-fold increased intensive care admission and 1.6-fold increased emergency surgery rates in patients with post-trauma hypotension as a sign of shock. In the recommendations by the American College of Surgeons Committee on Trauma [1], hypotension is considered an important criterion for admission to a trauma center. According to Smith et al. [21], hypotension is used consistently as a criterion for trauma team activation in all hospitals within the state of New South Wales in Australia. In a review of the New York State Trauma Registry, Henry et al. [8] reported mortality rates of 32.9 % in trauma patients with SBP (systolic blood pressure) < 90 mmHg and 28.8% for those with a respiratory rate < 10 or > 29/min.

Gunshot Wounds

Sava et al. [20] found that a gunshot wound to the torso, as sole activation criterion, has comparative predictive value to the previously used TTAC (trauma team activation criteria). In a subgroup with gunshot wounds to the abdominal/pelvic region, the frequency of severe injuries was the same in groups with and without TTAC (74.1 % and 70.8 %, p = 0.61). Tinkoff et al. [22] found a significant correlation between gunshot wounds to the torso or neck and admissions to the intensive care unit (see below). This criterion was also predictive for severe or fatal injuries and/or for emergency surgery. In a retrospective analysis, Velmahos et al. [6] reported an overall survival rate over 5.1 % in patients without vital signs in the emergency department after penetrating gunshot and stab wounds. In a review (25 years, 24 studies), Rhee et al. [18] identified a survival rate of 8.8 % after emergency thoracotomy in penetrating trauma.

In its last edition (2014), the ACS COT [1] listed various, weighted triage criteria. The Step One and Step Two criteria require transfer to a level 1 or 2 trauma center. Step One criteria include a) GCS below 14, b) SBP below 90 mmHg, or c) respiratory rate (RR) below 10/min or over 29/min. Step two criteria are a) penetrating injuries to the head, neck, torso, or proximal long bones, b) flail chest, c) fracture of two or more proximal long bones, d) amputation(s) proximal to the hands/feet, e) unstable pelvic fractures, f) open skull fractures, and g) spinal cord injuries. At present, there is relatively little evidence for these criteria. In a study of 1473 trauma patients, Knopp [9] found a positive predictive value (PPV) of 100% for ISS > 15 in spinal cord and amputation injuries; however, fractures of the long bones had a PPV of only 19.5%.

Tinkoff et al. [22] assessed several of these criteria for accuracy in the identification of severely injured and/or high-risk patients. Trauma patients fulfilling the ACS COT criteria had more severe injuries, increased mortality, and longer intensive care stays than control patients. Systolic blood pressure under 90 mmHg, endotracheal intubation, and gunshot wound to the torso/neck were predictive for emergency surgery or intensive care admission. Mortality was markedly increased in patients with SBP under 90 mmHg, endotracheal intubation, or GCS less than 9. Kohn et al. [10] analyzed various trauma team activation criteria (see Table 1), which are similar to those of the ACS COT. Respiratory rate under 10 or over 29 breaths per minute was the most predictive for presence of a severe injury. Other highly predictive parameters were: a) burns with over 20 % body surface area (BSA), b) spinal cord syndrome, c) systolic blood pressure under 90 mmHg, d) tachycardia, and e) gunshot wounds to the head, neck, or torso.

Open Head Injuries

With a lack of studies on the relevance of open head injuries, this criterion is regarded by the ACS COT rather as a significant indicator of severe injuries that require a high level of specialist medical competence and is thus assigned to the Step One criteria.

GCS

Kohn et al. [10] regard a GCS under 10 as an important predictor of severe trauma. Of patients activating the emergency department trauma team for low GCS, 44.2% had confirmed severe injuries. The value of GCS as predictor of severe injury or as activation criterion for the trauma team has been confirmed in studies by Tinkoff et al., Norwood et al., and Kühne et al. [11, 16, 22]. Norwood and Kühne both saw pathological intracerebral findings and need for inpatient admission already at GCS values under 14. At the same time, trauma team activation does not appear absolutely necessary with these patients (GCS $\leq$ 14 and $\geq$ 11). For GCS under 10, Engum [5] found a 70 % sensitivity for the endpoints surgery, intensive care unit (ICU), or death. The odds ratio (OR) was 3.5 (95% CI: 1.6-7.5). The authors found a PPV of 78 % for severe injuries in children with a GCS < 12.

Key recommendation:

2.8	Recommendation	2011
GoR B	**The emergency department trauma team should be mobilized for the following additional criteria:**	
	•Falls from over 3 meters	
	•Motor vehicle accident (MVA) with	
	•Frontal collision with intrusion greater than 50-75 cm	
	•Vehicle speed change of delta > 30 km/h	

•**Pedestrian/bicycle collision**
•**Occupant mortality (driver or passenger)**
•**Occupant ejection (driver or passenger)**

Explanation:

Accident-related/dependent criteria

In the literature, accident-related/dependent criteria are evaluated very differently regarding predictive value for severe trauma.

Norcross et al., Bond et al., and Santaniello et al. [2, 15, 19] report rates of overtriage up to 92%, sensitivity of 50-70 %, and PPV of 16.1% when accident-related mechanisms are used as the sole criterion for predicting injury severity. When physiological criteria are added, sensitivity of 80 % and specificity of 90 % are reached [2].

Knopp et al. found poor positive predictive values for the parameters of motor vehicle accident (MVA) with ejection or death of an occupant (driver or passenger) and MVAs involving a pedestrian [9]. Engum et al. also found the lowest predictive values for MVAs involving a pedestrian at 20 mph (miles per hour) and MVAs with occupant death and trauma from vehicle rollover [5]. The current ACS COT recommendations removed vehicle rollover trauma from the criteria. Frontal impact with intrusion greater than 20-30 inches, death of a car occupant, MVA with pedestrian/bicycle collision with $\geq$ 20 mph, and ejection of an occupant were cited as Step Three Criteria, i.e., there is no absolute necessity to transport these patients to a maximum care level hospital, provided these are isolated criteria. Kohn et al. [10] also consider vehicle rollover trauma as inadequate. According to Kohn et al., the same also applies to the criteria of MVA with occupant ejection or death and MVA with pedestrian involvement [10].

Champion et al. [3] consider vehicle rollover an important indicator of severe injury. The average probability of suffering a lethal injury is much higher in an overturned vehicle than in those not rolling over.

Nevertheless, the ACS COT removed the rollover mechanism from its triage criteria because relevant injuries after this type of accident should already be included in Step One or Step Two.

Vehicular Body Damage

In a multivariate analysis of 621 patients, Palanca et al. [17] found no significant association between vehicle deformation (intrusion of > 30 cm or > 11.8 inches) and the presence of relevant severe injury (OR: 1.5; 95% CI: 1.0–2.3; p = 0.05). Henry reported comparable results in another multivariate analysis [8]. Using data from the National Automotive Sampling System Crashworthiness Data System (NASS CDS), Wang found a PPV of 20% for ISS > 15 [24].

Occupant mortality (driver or passenger)

Knopp et al. found increased risks for surgery or death when a car occupant was fatally injured (OR: 39.0; 95% CI: 2.7–569; PPV 21.4%) [9]. Palanca et al. [17] did not confirm a significant association between occupant mortality and severe injury, although the concurrence of the two was 7 %.

Falls from a great height

In a prospective study by Kohn et al. [10], 9.4% of patients falling from more than 6 meters had severe injuries - defined as requiring intensive care admission or immediate surgery. Yagmur et al. [25] reported 9 meters as the average fall height from which patients died.

Burns

It is essential to determine whether burns are present without concomitant injuries. In the case of combination injuries where the non-thermal component is predominant, the patient should be brought to a trauma center [1].

Age

A 2015 review study identified age cutoffs between 45 and 70 years. Patients older than the respective cutoff should be treated in a trauma center by the trauma team. In addition to extended monitoring, surgical management should be adapted according to age-related pathophysiology. Treatment in trauma centers with geriatric expertise can reduce trauma-associated mortality of older patients.

Kohn et al. [10] evaluated various trauma team activation criteria similar to those of the ACS COT. Of the evaluated criteria, “age over 65” had the least informative value. Thus, the authors recommended that this criterion be removed from the “first-tier activations.” Demetriades et al. [4] found markedly higher mortality (16 %), increased ICU admission and need for surgery (19%) in patients over 70 years of age compared to younger patients. However, in this study, all patients not requiring hospital admission were excluded, so the cited percentages are probably overestimations. In a retrospective study of over 5000 patients from the DGU trauma registry, Kühne et al. [12] found increased mortality - irrespective of ISS - with increasing age. The cutoff value for increased mortality was 56 years. MacKenzie et al. [13] also found a marked increase in (fatal) injuries with age > 55 years. In a 13-year review, Grossmann et al. [7] found that mortality increased 6.8 % per year of life after 65. In a study by Morris et al. [14], patients who died from the consequences of an accident had lower ISS than younger patients in the control group.

Overall, the influence of age on trauma outcomes is a controversial topic. The ACS COT has classified age as a relatively low indication to transfer to Level 1 or 2 trauma center (Step Four criterion). Hildebrand considers age as a relevant influencing variable; however, accompanying medication, physiological reserves, and weak immune systems should be taken into account when evaluating geriatric patients (see above).

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2.4 Thorax

Importance of the Medical History

Key recommendation:

2.9	**Recommendation**	**2016**
GoR B	**An accurate medical history should be collected, if necessary from a third party.**	
2.10	**Recommendation**	**2016**
GoR B	**High-speed trauma and motor vehicle accidents with lateral impact should be considered evidence for chest trauma/aortic rupture.**	

Explanation:

Although there are few studies on collecting the medical history in regard to thoracic trauma, it remains an indispensable requirement for the assessment of injury severity and pattern of injury, and is used to establish whether or not an accident actually occurred. Collection of the circumstantial details of the accident are essential for the history. For motor vehicle accidents (MVAs) involving passenger vehicles, questions regarding the speed of the vehicle at the time of impact and the direction of impact are particularly important. There are marked differences in the occurrence, pattern, and severity of chest injuries as well as overall injury severity depending on whether the impact is lateral or frontal [113].

Horton et al. [64] reported a sensitivity of 100% and a specificity of 34% for aortic rupture with a lateral collision and/or change in velocity (delta V) $\geq$ 30 km/h. In another study [33], high velocity injuries at speeds of $>$ 100 km/h were graded as suspicious for aortic rupture. Richter et al [106] also found an increased risk of chest injury in lateral collisions. In this study, delta V correlated with the AIS (thorax), ISS, and clinical course. Ruchholtz et al. [110]

diagnosed chest injury in 8 of 10 passenger vehicle accidents involving lateral collision.

In a study of 286 passenger vehicle occupants with ISS $\geq$ 16, the probability of aortic injury was twice as high after lateral versus frontal collision [98]. Impact in the region of the superior thoracic aperture and fractures of ribs 1-4 appear to be associated with an increased incidence of aortic injuries [115].

Children as well have a 5-fold higher risk of severe chest injury (AIS $\geq$ 3) and significantly higher overall injury severity when they are occupants of a passenger vehicle in a lateral versus frontal collision [96].

The effect of seatbelts on chest injuries appears unclear. In a retrospective study of 1124 patients with relatively minor overall injury severity (ISS 11.6), Porter and Zaho [100] did find increased incidence of sternum fractures (4 % vs. 0.7 %) in seat belted patients, but the proportion of patients with thoracic injuries were identical in both groups (21.8 vs. 19.1 %).

Importance of Physical Examination Findings

Key recommendation:

2.11	**Recommendation**	**2016**
GoR A	**Clinical examination of the chest must be performed.**	
2.12	**Recommendation**	**Modified 2016**
GoR A	**Auscultation must be carried out with the physical examination.**	

Explanation:

Although there are barely any studies on the importance of and required scope for physical examination, it remains an indispensable requirement for the recognition of symptoms and making (suspected) diagnoses. The physical examination serves to detect relevant, life-threatening, or potentially fatal disorders or injuries that require immediate and specific treatment. Even when an examination has already been performed in the pre-hospital phase and even when a chest tube has already been inserted, physical examination in the emergency department is to be performed, since a change in the constellation of findings could have occurred.

The initial physical examination should address the following objectives [81]:

- Examination and securing of the airway
- Respiratory rate/dyspnea
- Inspection of the chest (skin and soft-tissue injuries, symmetry of the chest and respiratory excursion, paradoxical respiration, congestion, belt marks)
- Palpation (subcutaneous emphysema, crepitus, points of tenderness)
- Auscultation (presence and quality of breath sounds bilaterally)
- Details regarding pain

The following immediately life-threatening injuries must be checked during the initial examination [3]:

- Airway obstruction
- Tension pneumothorax
- Open pneumothorax
- Flail chest/Lung contusion
- Massive hemothorax
- Pericardial tamponade

Auscultation findings are the leading indicators in the diagnosis of chest trauma. In addition, subcutaneous emphysema, palpable instability, crepitus, pain, dyspnea, and increased ventilatory pressures can indicate thoracic injuries.

In a prospective study, Bokhari et al. [9] examined 676 patients with blunt or penetrating chest injury for clinical signs and symptoms of hemopneumothorax. Of 523 patients with blunt trauma, only 7 had hemopneumothorax. In this group, auscultation had sensitivity and negative predictive values of 100 %. Specificity was 99.8 % and the positive predictive value was 87.5 %. In penetrating injuries, the sensitivity of auscultation was 50 %, specificity and positive predictive value were 100 %, and the negative predictive value was 91.4 %. In both injury mechanisms, pain and tachypnea are insufficient to diagnose hemopneumothorax.

In a retrospective study of 118 patients with penetrating trauma, Chen et al. [21] also found a sensitivity of only 58%, specificity and positive predictive value of 98%, and a negative predictive value of 61% for auscultation. In a prospective study of 51 patients with penetrating trauma, the combination of percussion and auscultation exhibited a sensitivity of 96%, specificity of 93%, and positive predictive value of 83% [61].

These studies show that in penetrating trauma, decreased or absent breath sounds generally indicate an underlying pneumothorax, and a chest drain should be inserted prior to x-ray.

In their search for a clinical decision-making tool to identify children with chest injuries, Holmes et al. [63] studied 986 patients, 80 of whom had a chest injury. This yielded an odds ratio (OR) of 8.6 for positive auscultation findings, OR of 3.6 for abnormal physical examination (reddening, skin lesions, crepitus, tenderness), and OR of 2.9 for elevated respiratory rate.

Importance of Diagnostic Equipment (chest radiograph, ultrasound, CT, angiography, ECG, laboratory tests) and Indications for Use

Key recommendations:

2.13	**Recommendation**	**Modified 2016**
GoR A	**If thoracic trauma cannot be ruled out, radiological diagnostic studies must be performed in the emergency department.**	
2.14	**Recommendation**	**2016**
GoR B	**Spiral CT of the thorax with contrast medium should be performed for any patient with clinical evidence or history suggestive of severe chest trauma.**	

Explanation:
As explained in points 1 and 2, both the mechanism of injury and the findings from the physical examination provide important information on the presence or absence of a chest injury. For this reason, a chest radiograph can be dispensed with if a trauma CT scan will be performed immediately and if a chest injury can be excluded based on the accident circumstances and at the same time there are no findings from the physical examination that make an intrathoracic injury probable.

Conversely, all patients with confirmed chest injury should undergo chest x-ray once immediately life-threatening injuries have been excluded and/or treated. The initial radiograph can enable diagnosis of pneumothorax and/or hemothorax, rib fractures, tracheobronchial injuries, pneumomediastinum, mediastinal hematoma, and pulmonary contusion [53]. For detailed diagnosis of the pattern of injury, computed tomography is the gold standard. If there is not enough time available, chest x-ray can be performed as primary diagnostic study, due to the low cost and good availability. Nevertheless, there is little evidence on sensitivity and specificity of the diagnosis of pulmonary or thoracic injuries.

A prospective study of 100 patients found that the most important thoracic injuries are evident on chest x-ray. The sensitivity of images with the patient standing upright was 78.7 % and supine was 58.3 % [58]. In a series of 37 patients who died within 24 hours of admission, McLellan et al. [83] identified 11 cases in which important injuries found at autopsy were not evident on chest x-ray. Of these, there were 11 cases of rib fractures, 3 sternum fractures, 2 diaphragmatic ruptures, and 1 intimal lesion of the aorta.

The chest x-ray gives sufficient accuracy, e.g. to establish a need for chest tube drainage. In a prospective study of 400 polytrauma patients, Peytel et al. [99] reported that all cases (n = 77) in which chest tubes were placed based on chest x-ray findings were correct.

However, numerous studies have found that intrathoracic injuries can be identified significantly more often on CT than on chest radiographs alone. It is especially superior for the detection of pneumothorax, hemothorax, lung contusion, and aortic injuries. Spiral CT with intravenous (I.V.) contrast is preferable [94]. With the use of multilayer versus single-layer spiral CT, the average whole-body examination time decreased from 28 to 16 minutes, and the initial diagnostic information was taken from real-time images on the monitor [76] The NEXUS criteria can be helpful for the decision for or against radiological diagnostic studies [107].

In a series of 103 severely injured patients, Trupka et al. [122] found that compared to radiographs, additional information regarding the basic thoracic trauma was evident in 65 % of patients (lung contusion n = 33, pneumothorax n = 34, hemothorax n = 21). There were direct therapeutic consequences resulting from this extra information for 63 % of these patients, the majority of whom required new or correction of existing chest tube placement.

In patients with relevant trauma (motor vehicle accidents with accident speeds $>$ 15 km/h, falls from a height $>$ 1.5 m), Exadaktylos et al. [38] identified no thoracic injuries on conventional radiographs in 25 of 93 patients. However, CT showed some considerable thoracic injuries in 13 of these 25 patients, including two aortic lacerations. In a prospective study, Demetriades et al. [28] performed spiral CT examinations of the chest in 112 patients with deceleration trauma, of whom nine patients were diagnosed with aortic rupture. Four of these patients had normal chest x-rays. Eight cases of aortic rupture were identified on CT. One patient had an injury to the brachiocephalic artery. Local hematoma was evident on CT, but the vessel itself was not visualized on the CT cuts. Even in patients without clinical signs of thoracic injury and with negative radiographic findings, chest injuries were evident on CT in 39% of patients, and in 5% of cases this led to a change in treatment [95].

Blostein et al. [8] concluded that routine CT is not generally recommended in blunt chest trauma, since of 40 patients studied prospectively with defined chest injuries, 6 patients had changes in treatment (5x chest tubes, 1x aortogram with negative result). The authors admitted as well that CT yields findings not visible on conventional radiographs in patients who are intubated and ventilated. In patients with an oxygenation index (PaO_2/FiO_2) $<$ 300, the CT can help estimate the extent of pulmonary contusion and to identify patients at risk for pulmonary failure. Moreover, patients in whom an incompletely decompressed hemothorax and/or pneumothorax could lead to further decompensation can be identified. In a retrospective study of 45 children [104] with 1) pathologic radiographic findings (n = 27), 2) abnormal physical examinations (n = 8), and 3) substantial impact to the chest wall (n = 33), CT identified additional injuries in 40%, leading to a change in treatment of 18%.

Although the supplementary diagnostic information of chest CT has become generally accepted for blunt thoracic trauma in the more recent literature [54], its benefit regarding clinical outcomes remains controversial and is not yet clear. A prospective study by Guerrero-Lopez et al. [56] found chest CT to be more sensitive in detecting hemo/pneumothorax, lung contusion, vertebral fractures, and chest tube misplacement, and led to changes in therapy in 29 % of cases. On multivariate analysis, no therapeutic correlation between CT and ventilation duration, intensive care stay, or mortality was established. The authors concluded that chest CT should be performed only for suspected severe injuries that can be confirmed or excluded.

Current studies have identified clear benefits from multilayer CTs of the chest when there is a defined indication. Brink et al. [15] evaluated routine versus selective use in 464 and 164 patients, respectively. Indications for routine CT were high-energy trauma, threatening vital signs, and severe injuries such as pelvic or vertebral fractures. Indications for selective CT were abnormal mediastinum, more than three rib fractures, pulmonary shadowing, emphysema, and thoracolumbar spine fractures. Injuries not evident on conventional radiographs were found in 43 % of patients undergoing routine CT. This led to treatment changes in 17 %. Of 7.9 % of patients with normal chest x-rays, Salim et al. [111] found pneumothorax in 3.3 %, suspected aortic rupture in 0.2 %, lung contusion in 3.3 %, and rib fractures in 3.7 %.

Summarizing results in the literature, the following criteria are indications for chest CT:

Indication criteria for chest CT (summarized according to [15, 107, 111]):

- Motor vehicle accident (MVA) Vmax > 50 km/h
- Fall from > 3 m height
- Patient ejected from vehicle
- Rollover trauma
- Substantial vehicle damage
- Pedestrian hit at > 10 km/h
- Bicyclist hit at > 30 km/h
- Entrapment
- Pedestrian hit by vehicle and flung > 3 m
- GCS < 12
- Vital/hemodynamic abnormalities (respiratory rate > 30/min, pulse > 120/min, systolic blood pressure < 100 mmHg, blood loss > 500 ml, capillary refill > 4 seconds)
- Severe concomitant injuries (pelvic ring fracture, unstable vertebral fracture, or spinal cord compression)

A retrospective multicenter analysis using the DGU trauma registry database found improved survival probability for patients who had initially undergone a full-body CT scan [65]. The use of full-body CT leads to a relative reduction in mortality of 25 % in TRISS and of 13% in the RISC score. CT was an independent predictor for survival on multivariate analysis.

Key recommendation:

2.15	Recommendation	Modified 2016
GoR B	An initial ultrasound of the chest should be performed in any patient with clinical signs of thoracic trauma (according to the eFAST framework), unless an initial spiral CT chest with contrast has been performed.	

Explanation:

In a prospective study of 27 patients, chest X-rays, ultrasound examinations, and CT were compared for diagnostic accuracy for pneumothorax. The ultrasound examination of the chest showed sensitivity and negative predictive value of 100 % and specificity of 94 % [108]. In another study comparing ultrasound with radiographs for the diagnosis of pneumothorax, ultrasound yielded sensitivity and positive predictive value of 95 % and a negative predictive value of 100 % [31]. However, emphysematous bullae, pleural adhesions, or extensive subcutaneous emphysema can distort ultrasound results.

As a retrospective study of 240 patients made clear, ultrasound ranks equally with the X-ray in diagnosing hemothorax. In 26 of these patients, hemothorax was confirmed by either chest tube or chest CT. Ultrasound and chest x-ray each showed sensitivity of 96%, specificity and negative predictive value of 100%, and positive predictive value of 99.5% [78].

In a prospective study of 261 patients with penetrating injuries, chest ultrasound had a sensitivity of 100% and specificity of 96.9% for detecting pericardial tamponade [109]. False negative ultrasound results occur, however, especially in patients with a larger hemothorax, which can conceal smaller hematomas of the pericardium [86]. Thus, ultrasound sensitivity was only 56% in this study.

A retrospective study of 37 patients with CT-confirmed pulmonary contusion found ultrasound sensitivity of 94.6%, specificity of 96.1%, and positive and negative predictive values of 94.6% and 96.1%, respectively [116].

Spiral CT chest with contrast excluded aortic injuries in patients without detected mediastinal hematoma, so that angiography was not necessary. Because of insufficient sensitivity, conventional CT examinations are less suited for exclusion of an aortic injury [32, 44, 87].

Aortogram is useful only in patients with inconclusive CT or with a periaortal hematoma without direct signs of aortic injury. There is now general consensus that spiral CT with contrast is suitable to exclude aortic rupture [18, 36, 85]. There is high probability that patients without detectable mediastinal hematoma have no aortic injury. Thus, the use of computed tomography can avoid a large number of unnecessary aortogram procedures. However, when brain CT scan is also necessary, it should be carried out before the chest CT as the use of contrast agent complicates the traumatic brain injury diagnosis.

As comparative studies on angiography have shown, CT showing no evidence of mediastinal hematoma has a negative predictive value of 100% for the injury of large intrathoracic vessels [103]. However, the study of Parker et al. [97] finds the specificity only 89 % because of 14 false positive results. It is thus recommended that angiography be performed for patients with CT scans showing para-aortic hematoma or blood collections around aortic branches as well as aortic contour irregularities. A negative CT scan with contrast definitively excludes aortic rupture [44, 91, 127].

In an analysis of 54 patients with surgically detected aortic ruptures, Downing et al. [30] showed sensitivity of 100% and specificity of 96% for spiral CT. In a prospective study of 1104 patients with blunt chest trauma, Mirvis et al. [90] found mediastinal bleeding in 118 cases, of which 25 patients had aortic ruptures. For aortic rupture, spiral CT yielded sensitivity and negative predictive value of 100%, specificity of 99.7%, and positive predictive value of 89%. In a retrospective study of chest CT, Bruckner et al. found a negative predictive value of 99%, positive predictive value of 15%, sensitivity of 95%, and specificity of 40%.

In another prospective study of 1009 patients, 10 patients had aortic injuries [34]. Spiral CT had sensitivity and negative predictive value of 100 %, specificity of 96 %, and positive predictive value of 40 % for direct signs of aortic injury.

In contrast to the prospective studies mentioned above, in a retrospective study of 242 patients, Collier et al. [25] found a sensitivity of only 90% and a negative predictive value of 99%; aortic injury was found during the autopsy of one patient with a normal CT who had subsequently died from the consequences of traumatic brain injury. In another retrospective study, angiography did not detect any aortic injury in 72 patients with intrathoracic hematoma but no evidence of a direct aortic or other intrathoracic vessel injury on CT scan [112].

Transesophageal echocardiography (TEE) is a sensitive screening test [16, 24, 126], but angiography was often also carried out afterwards [19, 89]. TEE requires an experienced examiner [51] and is generally not as rapidly available as CT or angiography. The benefit of TEE may lie in the visualization of small intimal tears [16] that might not be visible on angiography or helical CT. However, TEE cannot provide good images of the ascending aorta and the aortic branches, which thus elude diagnostic evaluation [92]. To date, only one prospective study compares spiral CT to TEE in the diagnosis of aortic injury. CT and TEE showed sensitivity of 73 and 93%, respectively, and negative predictive value of 95%.

Key recommendations:

2.16	**Recommendation**	**2016**
GoR A	**A 3-lead ECG must be performed to monitor vital functions.**	
2.17	**Recommendation**	**Modified 2016**
GoR A	**If blunt cardiac injury is suspected, a twelve lead ECG must be performed.**	

Explanation:

An initial ECG is essential for every severely injured patient. It is necessary particularly in the absence of palpable pulses, to differentiate rhythms that can and can't be defibrillated in cardiac arrest. The ECG can also be used as a screening test for potential cardiac complications from blunt cardiac injury.

Patients with normal ECG, normal troponin-I value, normal hemodynamics, and no other relevant injuries do not require further diagnostic studies or treatment. Cardiac enzymes are irrelevant in predicting complications from blunt cardiac injury, although raised troponin I levels can predict abnormalities on echocardiography. A 12-lead ECG is performed for further diagnosis of patients with blunt chest trauma [23].

Echocardiography should not be used in the emergency department for the diagnosis of cardiac contusion, since this entity is not correlated with clinical complications. Echocardiography should be performed in hemodynamically unstable patients to diagnose pericardial tamponade or pericardial rupture. Transthoracic echocardiography should be the method of choice, as there is no clear evidence as yet that transesophageal echocardiography is superior in diagnosing blunt cardiac injury.

The ECG is a rapid, cost-effective, non-invasive examination that is always available in the emergency department. Meta-analysis of 41 studies found that ECG and creatine kinase MB (CK-MB) levels are more important than radionuclide examinations and echocardiogram in the diagnosis of clinically-relevant blunt cardiac injury (defined as a treatment-requiring complication) [79].

Fildes et al. [43] reported prospectively on 74 hemodynamically stable patients with normal initial ECG, no existing heart disease, and no other injuries. None of these patients developed cardiac complications. Another retrospective study of 184 children with blunt cardiac injury reported that patients with a normal ECG in the emergency department did not develop complications [29]. Meta-analysis of 41 studies correlated abnormal admission ECG with the development of treatment-requiring complications [79]. Conversely, a prospective study from Biffl et al. [7] identified contusion complications in 17 of 107 patients. Only two of 17 patients had abnormal ECG on admission, and three showed sinus tachycardia. In another retrospective study of 133 patients with clinical suspicion of myocardial contusion at two institutions, 13 patients (9.7 %) developed complications; however, no patients with normal initial ECGs showed other abnormalities [41]. In a study by Miller et al. [88] of 172 patients, four developed treatment-requiring arrhythmias, with all four patients having abnormal initial ECGs. Wisner et al. [134] studied 95 patients with suspected cardiac contusion. Of these, four patients developed clinically significant arrhythmias, and only one of these had a normal ECG on admission. In summary, the majority of authors recommend that asymptomatic, hemodynamically stable patients with normal ECG do not require any further diagnostic tests or treatment.

Key recommendation:

2.18	**Recommendation**	**Modified 2016**
GoR 0	**Serum levels of troponin can be measured as an adjunct for the diagnosis of blunt cardiac injury.**	

Explanation:

The assessment of creatine kinase MB (CK-MB) levels is not indicated for the diagnosis of myocardial contusion [23]. In a retrospective study of 359 patients, of whom 217 were initially admitted to exclude myocardial contusion, 107 were diagnosed because of either abnormal ECG or elevated CK-MB levels 16% of patients developed complications requiring treatment (arrhythmias or cardiogenic shock). All of these patients had abnormal ECG, but only 41% had elevated CK-MB levels. Patients with normal ECG and increased CK-MB levels did not develop complications [7]. In a prospective study of 92 patients undergoing ECG, CK-MB analysis, and continuous monitoring, 23 patients developed arrhythmias requiring no specific treatment. This shows that the number of arrhythmias requiring therapy is low. 52% of patients with arrhythmias had elevated CK-MB levels, whereas 19% of patients without arrhythmias also had elevated CK-MK levels [39]. Other studies have found no correlation between elevated CK-MB levels and cardiac complications [45, 57, 59, 71, 88, 117, 134].

Troponin I and T are sensitive markers in the diagnosis of myocardial infarction and considerably more specific than CK-MB, as they are not present in skeletal muscle. In a study of 44 patients, the 6 patients with echocardiography-confirmed myocardial injury showed simultaneous elevations in CK-MB and troponin I. Of the 37 patients without cardiac injury, CK-MB levels were elevated in 26 patients, but troponin I was elevated in none [1]. Another study of 28 patients, 5 of whom with echocardiogram-confirmed myocardial contusion, reported 100 % specificity and sensitivity for troponin I. In a study of 29 patients, troponin T showed higher sensitivity (31%) than CK-MB (9%) in diagnosing myocardial injury. Troponin T showed a sensitivity of 27 % and a specificity of 91 % for predicting clinically significant ECG changes in 71 patients [46].

In a more current prospective study of 94 patients, 26 patients were diagnosed with myocardial contusion by either ECG or echocardiography. Troponin I and T showed sensitivity of 23 and 12%, respectively, sensitivity of 97 and 100%, respectively, and negative predictive value of 76.5 and 74%, respectively. The authors describe an unsatisfactory correlation between the two enzymes and the occurrence of complications [6]. In another prospective study, sensitivity, specificity, and positive and negative predictive values of troponin I are given as 63, 98, 40, and 98%, respectively, for detecting myocardial contusion [35]. Velmahos et al. carried out ECG tests and troponin I measurements prospectively in 333 patients with blunt chest trauma [124]. In 44 diagnosed cardiac injuries, the ECG and troponin I showed sensitivity of 89 and 73%, respectively, and negative predictive values of 98% and 94%, respectively. The combination of ECG and troponin I produced sensitivity and negative predictive values of 100% each. Rajan et al. [102] showed that a cTnI level below 1.05 μg/l at admission and after six hours excludes myocardial injury.

Patients with a normal ECG and Troponin I values do not have myocardial contusion, and therefore need monitoring. It is different when the ECG is normal but the troponin I value is elevated; monitored observation is then recommended [23].

A transthoracic echocardiography (TTE) is often carried out in the diagnosis of blunt cardiac injury but has hardly any importance in hemodynamically stable patients. In a prospective study, Beggs et al. carried out TTE in 40 patients with suspected blunt chest injury. Half of the patients had at least one pathologic finding on ECG, TTE, or in the cardiac enzyme levels. There was no correlation between TTE, enzymes, or ECG findings, and TTE did not predict the development of complications [5]. In another prospective study of 73 patients undergoing TTE, CK-MB measurements, and cardiac monitoring, 14 patients had abnormalities on echocardiography. However, only 1 patient, who had a pathologic ECG on admission, developed a complication, in the form of a ventricular arrhythmia [60]. A prospective study of 172 patients offered the conclusion that only abnormal ECG or shock have predictive value with reference to monitoring or to specific treatment. Patients with abnormalities on TTE or elevated CK-MB levels without pathologic ECG developed no complications requiring treatment [88]. Although there are a number of studies showing the advantages of TTE in the diagnosis of pericardial effusion or pericardial tamponade in penetrating trauma, the value of this study for blunt trauma is debatable [88, 93, 109].

There are a number of studies showing that the accuracy of transesophageal echocardiography (TEE) is greater than that of TTE in the diagnosis of cardiac injuries [16, 20, 22, 52, 130]. In addition, other cardiovascular changes such as aortic injuries, for example, can be diagnosed by TEE. In a prospective study of 95 patients with risk factors for aortic injury, Vignon et al. [125] performed spiral CT and then TEE in the intensive care unit. The sensitivity of TEE and CT was 93 and 73%, respectively, the negative predictive values were 99% and 95%, respectively, and the specificity and the positive predictive values were 100% for both examination methods. TEE proved superior in identifying intimal tears, whereas an aortic branch lesion was missed. In summary, echocardiography should be carried out if a pericardial tamponade or pericardial rupture is suspected.

Additional Diagnostic Studies Available for Trauma Patients in the Emergency Department

Fabian et al. [40] state that patients with mediastinal hematoma and no direct evidence of aortic injury require no further assessment. This also applies to intimal tears and pseudo-aneurysms. However, patients with changes that cannot be classified in more detail should undergo angiography for further assessment. Gavant et al. [49] also stated that in the absence of a mediastinal hematoma or if a normal aorta is visualized despite mediastinal hematoma, spiral CT with contrast agent is sufficient for diagnosis and aortography is not necessary.

Mirvis et al. [90] and Dyer et al [34] suggest that aortic injury or injury to the main branches and a mediastinal hematoma detected on CT require either angiography or direct thoracotomy, depending on the experience of the treating establishment. Angiography is also necessary for mediastinal hematoma in direct contact with the aorta or the proximal great vessels without direct evidence of vascular injury or for abnormal aortic contours [97].

Downing et al. [30] conclude that surgical treatment can be carried out without further diagnostic tests if spiral CT clearly detects an aortic rupture. In contrast to the study by Dyer et al. [33] mentioned above, Fabian et al. [40] conclude that patients with mediastinal hematoma but no direct evidence of aortic injury require no further work-up.

To date, there are no comparative studies evaluating the need for angiography prior to a planned operation for an aortic injury detected on CT scan. Thus, the recommendations are based both on conclusions from studies evaluating angiography and CT in the diagnosis of aortic injury and on data from diagnostic tests performed prior to endovascular treatment.

Gavant et al. [49], recommend that aortography be carried out prior to surgical or endovascular treatment to confirm the injury and define the extent of damage. Parker et al. [97] also consider angiography necessary to confirm positive CT findings.

In patients with direct evidence of aortic injury and mediastinal hematoma, Mirvis et al. [90] and Dyer et al [34] suggest either angiography or direct thoracotomy, depending on the experience of the treating establishment.

Downing et al. [30] and Fabian et al. [40] hold the view that thoracotomy can be carried out with a clear CT diagnosis, also without additional angiography.

In a series of five patients with acute traumatic rupture of the thoracic aorta, CT scans and angiography were carried out on all patients prior to stent implantation [119].

Importance of Emergency Measures (chest tube drainage, intubation, pericardiocentesis, thoracotomy)

Key recommendations:

2.19	**Recommendation**	**2016**
GoR A	**Clinically relevant or progressive pneumothorax must be primarily decompressed in ventilated patients.**	
2.20	**Recommendation**	**2016**
GoR B	**For non-ventilated patients, progressive pneumothorax should be decompressed.**	
2.21	**Recommendation**	**2016**
GoR A	**A chest tube must be inserted for this purpose.**	
2.22	**Recommendation**	**Modified 2016**
GoR B	**Chest tubes sized 24 - 32 French should be favored.**	

Explanation:

A pneumothorax detected on x-ray is an indication to insert a chest tube, particularly when mechanical ventilation is necessary. This is general clinical practice, although there are no comparative studies examining this in the literature [2, 47, 50, 63, 129]. Because of the underlying pathophysiology, it has been upgraded to Grade of Recommendation A. Westaby and Brayley [132] recommend that a chest tube should always be inserted for pneumothorax larger than 1.5 cm at the level of the 3rd intercostal space. If it is smaller than 1.5 cm, the chest tube should only be placed if ventilation is necessary or if both sides are affected. Chest tube placement can be omitted in a small anterior pneumothorax detected on CT only, but close clinical monitoring is required.

Chest tubes should be placed in the emergency department since there is a risk of progression to tension pneumothorax, and the rapidity of this development cannot be estimated. The risk of a tension pneumothorax occurring should be considered markedly higher in ventilated patients versus non-ventilated patients. In non-ventilated patients, a small pneumothorax less than 1-1.5 cm wide can initially be treated conservatively with close clinical observation. If this is not possible because of logistics, decompression of the pneumothorax should also be performed here.

The benefits of a very large lumen chest tube 36-40 vs. 28-32 Fr have not been confirmed in polytrauma patients. This was investigated in a study of 293 patients [67]. On the contrary, smaller chest tubes (24 Fr) can be used without complications.

The increasing use of abdominal and chest CT in the diagnosis of blunt trauma has led to the detection of pneumothorax cases that would not have been detected on conventional supine radiographs. These cases of "occult pneumothorax," usually lying anteriorly, are found in 2-25% of patients after severe multiple injuries [8, 95, 105, 121, 122, 128]. Based on the available literature, the initial insertion of a Bülau drain should be omitted in an occult pneumothorax diagnosed by CT if:

- the patient is hemodynamically stable and has largely normal pulmonary function,
- there are frequent clinical checks, with the possibility of interval x-rays,

and

- a chest tube can be inserted at any time by a qualified physician [72].

In a prospective randomized study, Brasel et al. [14] also studied the need for chest tube insertion for an occult traumatic pneumothorax. Chest tubes were inserted in 18 patients, and 21 patients were observed only. Ventilation was necessary for nine patients of each group. In the chest tube group, the pneumothorax increased in 4 patients; in the control group without chest tubes, a Bülau drain was inserted in 3 patients, of whom 2 were then also ventilated.

In a prospective study of 36 patients with 44 cases of occult pneumothorax, cases were subdivided into minimal ($<$ 1 cm visible on a maximum of 4 CT slices), anterior ($>$ 1 cm but not extending laterally into the dorsal half of the chest), and anterolateral pneumothorax [135]. Fifteen cases of minimal pneumothorax were monitored closely, regardless of the need for ventilation. Two cases required secondary insertion of a chest tube. In patients requiring ventilation, anterior and anterolateral pneumothorax was always treated with chest tube placement. In a prospective study of children, Holmes et al. identified eleven patients with occult pneumothorax, classified according to the schema above [62]. Patients with minimal pneumothorax were treated conservatively regardless of need for ventilation.

In a retrospective study, 13 pneumothorax patients were treated with and 13 without chest tube insertion [26]. Of ten patients in whom mechanical ventilation was needed, two patients required secondary chest tube placement. However, there was no information regarding the size of the initial pneumothorax. In another retrospective study, the size of the occult pneumothorax was compared against the need to insert a chest tube, and it was suggested that pneumothorax less than 5 x 80 mm could be observed regardless of the need for mechanical ventilation [48]. In their retrospective study of 1199 patients (403 with traumatic pneumothorax), Weißberg et al. [131] stated that clinical observation is possible for cases of pneumothorax less than 20 % of the pleural space. There are no details regarding the possible effects of mechanical ventilation.

A score was proposed by de Moya to better define a "small" pneumothorax, comprised of two parts: 1) the largest diameter of the pneumothorax, and 2) its relationship to the pulmonary hilum. If the pneumothorax does not exceed the pulmonary hilus, 10 is added to the millimeter measure of the pneumothorax; if the hilus is exceeded, 20 is added. The score value is the sum of the individual values of each side. The positive predictive value for a chest tube with a score $>$ 30 was around 78 % and the negative predictive value for a score $<$ 20 was around 70 % [27]. In a randomized study of 21 ventilated patients, observation of occult pneumothorax was shown to be safe. In 13 patients treated initially without chest tube placement, emergency decompression was required in none, although two patients required evacuation of pleural effusion over the course of stay and one patient required decompression of a progressive pneumothorax after central venous catheter placement. A "wait and see" attitude regarding chest tube insertion for occult pneumothorax appears justified in ventilated and non-ventilated patients [4, 133].

In an analysis of patients with traumatic cardiac arrest, decompression of tension pneumothorax was identified as the most important factor leading to improved prognosis [66]. In addition, non-decompressed tension pneumothorax has been reported as the most frequent definitively avoidable cause of death after trauma [75]. For this reason, resuscitation after trauma should not be ended until the reversible cause "tension pneumothorax" is definitely excluded [74].

Key recommendations:

2.23	Recommendation	2016
GoR B	**Pericardial decompression should be performed for confirmed cardiac tamponade and acute deterioration of vital parameters.**	

2.24	Recommendation	New 2016
GPP	**For hemodynamically unstable patients with thoracic trauma, an eFAST examination should be performed to rule out pericardial tamponade.**	

Explanation:
Regardless of the patient's condition, the diagnosis of pericardial tamponade should be rapidly and reliably made so that any necessary surgery can be carried out rapidly. Although the diagnosis of tamponade can be confirmed by the insertion of a pericardial window, this is an invasive procedure, particularly if there is only mild suspicion of cardiac injury. The ultrasound examination has proven itself as a sensitive study to diagnose pericardial effusion and is thus the current method of choice. In a prospective multicenter study of 261 patients with penetrating pericardial chest injuries, sensitivity was 100%, specificity 96.7%, and accuracy 97% [109]. There were no false negative results. In another study, ultrasound identified pericardial fluid in three of 34 patients. One patient was hemodynamically unstable and underwent thoracotomy, and the other two had negative pericardial windows [10].

Pericardiocentesis is now of lesser importance in the diagnosis of pericardial tamponade, having been replaced by ultrasound examination [23, 109, 120].

Key recommendation:

2.25	Recommendation	2016
GoR 0	**Thoracotomy can be performed with initial blood loss > 1500 mL from the chest tube or with continuing blood loss > 250 mL/hour for more than 4 hours.**	

Explanation:
There was intensive debate within the guideline group regarding indications for thoracotomy depending on the initial or continuing blood loss through the chest tubes, not least because of the inconsistent quantities reported in the literature. These are almost exclusively cohort studies on penetrating trauma; randomized studies on this topic are not available. The evidence is much less clear for blunt trauma; thoracotomy is indicated in far fewer cases and generally later than for penetrating trauma. In certain conditions with corresponding blood loss, thoracotomy can be useful even in hemodynamically stable patients. There is no data regarding coagulation status as criterion for decision-making; however, body temperature can be taken into account.

In the 1970s, based on experience with penetrating trauma in the Vietnam War, McNamara et al. [84] reported reduced mortality after early thoracotomy. The indication criteria for thoracotomy were given as initial blood loss of 1000-1500 ml after chest tube insertion as well as blood loss of 500 ml in the first hour after tube placement.

Kish et al. [73] evaluated 59 patients in whom thoracotomy was necessary. Thoracotomy was performed 6-36 hours post-trauma when there was continuous bleeding of 150 ml/h over more than 10 hours or 1500 ml over a shorter time period in four of 44 cases of penetrating and two of 15 cases of blunt trauma. The strategy of thoracotomy for an initial blood loss > 1500 ml after chest tube placement or with continuous blood loss > 250 ml over 4 hours has been accepted for penetrating injuries [80].

A multicenter study of 157 patients undergoing thoracotomy for thoracic bleeding found an association of mortality with the level of thoracic blood loss [69]. Mortality risk increased 3.2-fold with a blood loss of 1500 ml versus 500 ml. The authors concluded that for patients with penetrating and blunt trauma, thoracotomy should be considered with a blood loss of 1500 ml in the first 24 hours after admission even when there are no signs of hemorrhagic shock.

In the current version of the NATO Handbook [11], initial blood loss of 1500 ml as well as drainage of 250 ml or more per hour over more than four hours are given as indications for thoracotomy. The various volumes reported as threshold values were gone over by the guideline group. Agreement was reached with the volume presented in the recommendation of > 1500 ml initially or > 250 ml/h over more than four hours.

Key recommendation:

2.26	Recommendation	2016
GoR B	**Emergency thoracotomy should not be performed in the emergency department for blunt trauma patients with absence of vital signs at the accident scene.**	

Explanation:
When vital signs are absent at the accident scene in blunt trauma patients, emergency thoracotomy in the emergency department is not indicated. Vital signs include pupillary reaction to light, any type of spontaneous breathing, movement to pain stimuli, or supra-ventricular activity on ECG [12]. However, if cardiac arrest develops on admission to the hospital, immediate thoracotomy should be performed, especially in the case of penetrating trauma.

Boyd et al. carried out a retrospective study of 28 patients undergoing thoracotomy in the emergency department for resuscitation. Meta-analysis was also performed [12]. Survival rate was 2 of 11 patients with penetrating trauma and 0 of 17 blunt trauma patients. Survival rate (2 of 3 patients) was highest when vital signs were present both at the accident scene and in the emergency department. Meta-analysis of 2294 patients yielded a survival rate of 11 %, with survival significantly better in penetrating versus blunt trauma (14 % vs. 2 %). There were no survivors in the group of patients without vital signs at the accident scene, and of blunt trauma patients without vital signs in the emergency department, none survived without neurological deficits.

Velhamos et al. [123] performed a retrospective analysis of 846 patients who underwent emergency thoracotomy in the emergency department. All patients presented without vital signs at the time of admission or with cardiac arrest in the emergency department. Of 162 patients who were successfully resuscitated, 43 (5.1 %) were discharged from the hospital, and 38 of these had no neurological deficit. Of 176 patients with blunt trauma, only one patient survived (0.2 %) with significant neurological deficits.

Branney et al. [13] reported an overall survival rate of 4.4 % in 868 patients undergoing emergency thoracotomy. Eight of 385 (2 %) blunt trauma cases survived. Of these, four patients had no neurological deficits. Of blunt trauma patients without vital signs at the accident scene, two patients survived with severe neurological deficits. In contrast, patients with penetrating trauma and without vital signs at the accident scene fared markedly better with 12 of 355 surviving neurologically intact. This result is clearly different from that obtained by the meta-analysis of Boyd et al. [12] outlined above, and later studies by Esposito et al. [37], Mazzorana et al. [82], Brown et al. [17] and Lorenz et al. [77], who found no survivors among patients with penetrating trauma without vital signs at the accident scene.

Another retrospective study of 273 thoracotomies performed in the emergency department yielded ten survivors without neurological deficits [68]. They all had penetrating injuries and vital signs were present either at the accident scene or in the emergency department. Of 21 blunt trauma patients, none survived. The authors conclude thus, that thoracotomy should be performed in the emergency department only for patients with penetrating trauma and evidence of vital signs either at the accident scene or in the emergency department. Grove et al. [55] also found no survivors of 19 blunt trauma patients treated with emergency thoracotomy. At the time of admission, five of these patients had no vital signs and 14 patients had positive vital signs. All patients died within four days. The survival rate for penetrating trauma was 3 of 10 patients.

Based on a meta-analysis of 42 outcome studies with a collection of 7035 emergency department thoracotomies, the American College of Surgeons published a guideline on the indications and implementation of emergency department thoracotomy [118]. The resulting conclusions are based primarily on the finding that with an overall survival rate of 7.8 %, only 1.6 % of blunt trauma patients, but 11.2 % penetrating trauma patients survived. More recent studies have also confirmed that emergency thoracotomy performed during cardiopulmonary resuscitation (CPR) can improve prognosis, particularly in penetrating trauma, and appears to be particularly expedient when vital signs are initially present [42, 70, 101, 114].

The evidence table for this chapter is found on page 169 of the guideline report.

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2.5 Abdomen

Key recommendation:

2.27	Recommendation	2011
GoR A	**The abdomen must be examined, although an unremarkable examination does not exclude a relevant intraabdominal injury, even in conscious patients.**	

Explanation:

In a prospective study of 372 hemodynamically stable patients after blunt abdominal trauma, Miller et al. reported that intra-abdominal injury was detected on CT in only 25.5 % of the 157 patients complaining of painful abdomen or pelvis. CT detected injury in only 20 % of patients with the "seatbelt sign" [20].

In a multicenter prospective study of 2299 patients with blunt abdominal trauma (exclusion criteria GCS $\leq$ 14, age $\leq$ 16 years, emergency laparotomy undergone), Livingston et al. [15] reported that a positive clinical examination related to signs of external injury or pain was present in 1406 (61 %) of patients. Evidence of abdominal injury on CT was present in only 26 % of these patients. Of patients with evidence of abdominal injury on CT, 11 % of patients had normal clinical examinations. Of 265 patients with free intra-abdominal fluid on CT, 212 (80 %) had abnormal clinical examinations. In this study, the sensitivity of the clinical examination for free fluid on CT was 85 %, the specificity 28 %, the positive predictive value 63 %, and the negative predictive value 57 %.

In a prospective study of 350 patients, Ferrara et al. investigated the predictive value of abdominal tenderness in association with the presence of an intra-abdominal lesion verified on CT or with diagnostic peritoneal lavage (DPL) [5]. They calculated a sensitivity of 82 %, a specificity of 45 %, and a positive predictive value of 21 %, with a negative predictive value of 93 %.

In a prospective study of 162 patients (2001-2003, Level I Trauma Center) after blunt trauma with clear level of consciousness (GCS $\geq$ 14) and unremarkable clinical abdominal examination (but requiring emergency extra-abdominal surgical intervention, 88 % trauma surgery, and CT scan of the abdomen), Gonzalez et al. [6] found that these patients do not need diagnostic CT prior to surgery, because the clinical examination is suitably reliable in this population. The diagnostic CT study provided pathological intraperitoneal findings in only two cases (1.2 %) that needed no further interventions (spleen injury, mesenteric hematoma).

Concomitant Injuries

In a study of 1096 patients with blunt abdominal trauma, Grieshop et al. [7] tried clinical options to identify patients not needing further diagnostic CT. Patients in shock with GCS < 11 or who had suffered spinal trauma were evaluated, but because of the limited clinical examination they were not included in the statistical evaluation (n = 140). The authors concluded that along with abnormal clinical examination (abdominal tenderness, guarding or other signs of peritonitis), the presence of macrohematuria or thoracic trauma (fractures of ribs 1 or 2, multiple rib fractures, sternum fracture, scapula fracture, widened mediastinum, hemo/pneumothorax) must also be considered risk factors. The risk of intra-abdominal injury increases by a factor of 7.6 with accompanying thoracic trauma and a factor of 16.4 with accompanying macrohematuria. All patients with relevant intra-abdominal injuries (n = 44) belonged either to the group with abnormal examination or to the group with one or both of the risk factors mentioned above (n = 253), corresponding to a sensitivity of 100 %. The authors continued that to exclude organ injuries, these cases must undergo additional diagnostic studies, for example with computed tomography of the abdomen. No abdominal injuries were evident in the remaining 703 patients with normal examinations and no risk factors. The calculated negative predictive value was 100 %, so that further diagnostic studies can be foregone in these cases. According to this study, associated bony pelvic injury, closed traumatic brain injury, spine injury, and fractured long bones of the lower extremity are not significant independent risk factors.

In contrast, in prospective studies, Ballard et al. and Mackersie et al. found that pelvis fractures are associated with increased risk of intra-abdominal organ injuries, so that diagnostic CT is needed for several reasons [2, 17].

Schurink et al. [34] evaluated the importance of the clinical examination in a retrospective study of 204 patients subdivided into four groups: patients with isolated abdominal trauma (n = 23), patients with lower rib fractures (ribs 7-12) (n = 30), patients with isolated head injury (n = 56), and patients with multiple injuries (ISS $\geq$ 18) (n = 95). All patients underwent abdominal ultrasound examinations. For the 20 patients with isolated abdominal trauma, clinical examination yielded sensitivity of 95 %, negative predictive value of 71 %, and positive predictive value of 84 % for the presence of intra-abdominal injury. For patients with rib fractures, the sensitivity and negative predictive value were 100 % with four abnormal clinical examinations.

Ultrasound

Key recommendations:

2.28	**Recommendation**	**2011**
GoR B	**Initial focused abdominal ultrasound screening for free fluid, "Focused Assessment with Sonography for Trauma" (FAST), should be performed.**	
2.29	**Recommendation**	**2011**
GoR B	**Ultrasound examinations should be repeated at intervals if computed tomography (CT) cannot be done in a timely manner.**	
2.30	**Recommendation**	**2011**
GoR 0	**If CT can't be performed, ultrasound examination focused on diagnosing parenchymal injuries in addition to FAST can be used as an alternative.**	

Explanation:
Stengel et al. performed a systematic review of four randomized, controlled studies on the value of ultrasound-based algorithms in the diagnosis of patients after blunt abdominal trauma; they found no evidence as yet to recommend ultrasound-based algorithms [39]. The same author previously carried out meta-analysis and systematic review on the diagnostic value of ultrasound as a primary investigative tool for detecting free fluid in the abdomen (FAST) (19 studies) or intra-abdominal organ injuries (11 studies) after blunt abdominal trauma. The 30 studies evaluated included investigations until July 2000 with 9047 patients and evidence levels IIb to IIIb [38]. One result was that abdominal ultrasound is only minimally sensitive in the diagnosis of free fluid and intra-abdominal organ injury. Every tenth organ lesion was not detected on primary ultrasound. Thus, ultrasound is considered insufficient as a primary diagnostic study after abdominal trauma, and other diagnostic studies (e.g. spiral CT) are recommended for both negative and positive findings [38, 39].

FAST
In a prospective study of 359 hemodynamically stable patients, Miller et al. assessed the importance of FAST using the hypothesis that a FAST examination leads to missed detection of intra-abdominal injuries after abdominal trauma [20]. As gold standard, abdominal CT was performed within one hour of the ultrasound in all patients. FAST was performed with four views and evidence of free fluid was considered a positive result. The FAST examination yielded 313 true-negative, 16 true-positive, 22 false-negative, and 8 false-positive results. This resulted in a sensitivity of 42 %, a specificity of 98 %, a positive predictive value of 67 %, and a negative predictive value of 93 %. Of the 22 false-negative diagnosed patients, 16 had parenchymal injuries to the liver or spleen, one each had mesenteric injury and gall bladder rupture, two had retroperitoneal injuries, and two other patients had free fluid without recognizable injury on CT. Six patients of this group required surgery and one underwent embolization with angiography. Among the 313 patients with true-positive FAST findings, the CT examination identified 19 additional hepatic and spleen injuries as well as eleven retroperitoneal injuries (including aortic wall hematoma, bleeding of the pancreatic head, kidney contusion). None of these patients required operative interventions. As a consequence, the authors call for further assessment with CT abdomen/pelvis for sufficiently hemodynamically stable patients, regardless of FAST examination findings [20].

In a systematic review by McGahan et al. of investigations assessing the importance of FAST as a diagnostic study after abdominal trauma, there was wide variation in the sensitivity of the examination for detection of free fluid, ranging from 63 to 100 %. McGahan et al. are critical of studies reporting high sensitivity and citing FAST as a suitable initial screening method, in which there are significant study design weaknesses (no standard reference, no consecutive inclusion) [19].

Soyuncu et al. reported on a prospective case series of 442 patients who had sustained blunt abdominal trauma. They found that FAST, performed by an examiner experienced in abdominal ultrasound (minimum one year experience), had a sensitivity of 86 % and a specificity of 99 % with 0.95 % false-positive and 1.1 % false-negative results (controls laparotomy, CT, autopsy) [37].

Ultrasound as Organ Diagnostic Study
In a prospective study of 55 hemodynamically stable patients, Liu et al. [14] compared the diagnostic value of ultrasound (with screening for free fluid and organ injury), computed tomography, and DPL on the same patients. DPL was performed after the imaging procedures so as not to distort the other studies. In the diagnosis of an intraabdominal injury (without differentiating between detection of free fluid and direct detection of organ injury), the authors found a sensitivity of 91.7 % and a specificity of 94.7 % for ultrasound, below the results of DPL and CT. The disadvantages of ultrasound are: (1) technical difficulty of ultrasound when subcutaneous emphysema is present, (2) prior to surgery, free fluid may not flow into the Douglas space and thus could elude diagnosis, (3) pancreas and hollow organ injuries might not be well assessed, and (4) poor ability to assess the retroperitoneal space. In conclusion, the authors recommended ultrasound because of its usability as a primary diagnostic tool in the examination of hemodynamically unstable patients. However, due to the limitations cited, they warned against overestimating its informative value.

In a study of 3264 patients, Richards et al. [29] evaluated the quality of abdominal ultrasound for the diagnosis of free fluid and organ parenchymal injuries after abdominal trauma. Distinct from the FAST examination, abdominal ultrasound in this study was explicitly focused on detecting parenchymal injuries of the liver, kidneys, and spleen. Results were verified using CT, laparotomy, DPL, or clinical observation. Free fluid was detected in 288 patients on ultrasound and controlled with CT and laparotomy. Sensitivity was 60 %, specificity 98 %, negative predictive value 95 %, and positive predictive value 82 % for the diagnosis of free fluid alone. Specific organ injuries were detected in 76 cases, 45 with concomitant free fluid. The contemporaneous targeted ultrasound for organ parenchymal injuries increased the sensitivity for diagnosis of intra-abdominal injury to 67 %.

Like Richards and Liu et al., Brown et al. [4] examined 2693 patients after abdominal trauma for free fluid and also targeted for parenchymal injuries. Of these, 172 had intra-abdominal injury verified with laparotomy, DPL, CT, the clinical course, or on autopsy. Hemoperitoneum was not detected on ultrasound in 44 patients (26 %), but organ lesions were diagnosed in 19 (43 %) of these patients. The authors conclude that by limiting an ultrasound to a short examination focused on detecting free fluid (FAST), organ injuries are overlooked. Thus, as an emergency diagnostic study, an ultrasound examination should be focused on detection of free fluid and injuries to the organ parenchyma.

In a prospective study of 800 patients, Healey et al. [8] found higher sensitivity (88 %) for the diagnosis of intra-abdominal injury. This study also screened for both free fluid and organ lesions, and the results were compared to CT, DPL, laparotomy, repeat ultrasound, or the progressive course.

Poletti et al. [28] used a comparable study design and reported higher sensitivity. They evaluated 439 patients after abdominal trauma. 222 of these patients underwent no further investigations after initial normal screening and were discharged with the instructions to return if they felt there was deterioration. The remaining 217 patients were assessed. Ultrasound showed sensitivity of 93 % (77 of 83 patients) for the detection of free fluid and sensitivity of 41 % (39 of 99 patients) for direct evidence of parenchymal organ injury, although hepatic injuries were diagnosed well compared to other organs. In a repeat examination in cases of primary negative findings, these values could be increased; however, pathology had already been identified on CT and was known by the examiner. Overall, 205 patients underwent CT follow up examinations.

McElveen et al. [18] evaluated 82 consecutive patients (for free fluid and organ lesions), performed controls for all patients with reference examinations (71 with CT, six with repeat ultrasound, three with DPL, and two with laparotomy) and followed up for one week after trauma, either in-hospital or as outpatient. With sensitivity of 88 % and specificity of 98 %, along with negative predictive value of 97 % for the diagnosis of intra-abdominal injury, they recommended ultrasound as the primary examination method after abdominal trauma.

Poletti et al. compared the diagnostic value of ultrasound (with and without intravenous contrast enhancement) with CT in a prospective study of 210 consecutive hemodynamically stable patients after blunt abdominal trauma. The patients first underwent conventional ultrasound (including targeted organ diagnosis) and then CT. Patients with false-negative findings on primary ultrasound initially underwent repeat conventional ultrasound and with renewed negative findings, an ultrasound enhanced with contrast agent. Poletti et al. [27] found that neither repeat conventional ultrasound nor contrast-enhanced ultrasound reached the quality of computed tomography for the detection of organ injuries. With computed tomography, 88 organ injuries (solid organs) were detected in 71 patients. Of 142 patients in whom CT did not detect free fluid (intra-abdominal or retroperitoneal), organ injuries (all organs) were evident in 33 (23 %). Four of these patients (12 %) required intervention (laparotomy/interventional angiography). Primary ultrasound recognized 40 % (35 of 88), the control ultrasound 57 % (50 of 88), and the contrast-enhanced ultrasound 80 % (70 of 88) of the solid organ injuries. The authors concluded that even contrast-enhanced ultrasound cannot replace CT in hemodynamically stable patients.

Repeat Examinations

Regarding the importance of repeat ultrasound monitoring of patients after abdominal trauma, Hoffmann et al. [10] found that of 19 (18 %) of 105 patients with initially unclear findings, free intra-abdominal fluid could only be detected on repeat ultrasound in the emergency department (after hemodynamic stabilization procedures). The authors point out that if possible, both ultrasounds should be performed by the same examiner to achieve optimal monitoring. The monitoring examination should be performed about 10-15 minutes after the primary ultrasound in patients with minimal evidence of fluid (1-2 mm border) or unclear findings on the initial exam. Compared to DPL, repeated ultrasound can document a possible increase in free fluid, and can also be used to diagnose retroperitoneal and intra-thoracic injuries.

In the study mentioned above, Richards et al. [29] reported an increase in ultrasound sensitivity.

In a prospective study of 156 patients after blunt or penetrating abdominal trauma, Numes et al. [25] found that the use of repeat ultrasound led to a 50 % reduction in the false-negative rate for free intra-abdominal fluid and with it, an increased sensitivity from 69 % (from a single scan) to 85 %.

Examiners

Regarding who must perform the investigation, Hoffmann et al. [10] believe that ultrasound screening for free abdominal fluid can be easily learned and can then be reliably carried out by a member of the emergency department trauma team. However, the type and amount of training necessary remains unclear.

A prospective study by Ma et al. [16] reported that a 10-hour theoretical introduction, coupled with implementation of 10-15 examinations on healthy subjects is sufficient to achieve diagnostic proficiency in emergency ultrasound of the abdomen, provided that this is restricted to detection/exclusion of free fluid.

McElveen et al. [18] make the same recommendation although it is not based on a study. They stipulate 15 examinations of normal patients and 50 monitored exams on trauma patients.

A retrospective study by Smith et al. [36] on the quality of the ultrasound by trained, experienced surgeons showed that extensive previous ultrasound experience is not required and there is no learning curve.

Although a comparative study is lacking, Brown et al. [4] call for screening to increase sensitivity of the ultrasound by including focus on specific organ lesions, and thus, recommend that the exam be carried out by an experienced practitioner.

Diagnostic Peritoneal Lavage (DPL)

Key recommendation:

2.31	Recommendation	2011
GoR A	**Diagnostic peritoneal lavage (DPL) must only be performed for exceptional cases.**	

Explanation:

With a sensitivity of 100 % and a specificity of 84.2 %, DPL was the most sensitive method for detecting intra-abdominal injury in the study by Liu et al. [14] comparing it to CT and ultrasound. The authors argue, however, that the high sensitivity (e.g. by detection of blood on catheter insertion) leads to a relevant number of non-therapeutic laparotomies. Liu et al. are also critical of DPL in cases of retroperitoneal hematoma, since even small tears in the peritoneum yielded positive results, which then led to unnecessary laparotomies in half of the six patients with retroperitoneal hematoma.

Hoffmann [10] considers the indications for DPL only in exceptional cases of patients impossible to examine with ultrasound (e.g. extreme obesity or abdominal wall emphysema), since in comparison to ultrasound and CT, DPL permits no conclusions regarding retroperitoneal injuries. Waydhas states that DPL is contraindicated in patients with previous laparotomy. In a prospective study of 106 polytrauma patients, the authors found a markedly lower sensitivity for ultrasound (88 %) versus DPL (95 %). Despite the lower sensitivity, they recommend ultrasound as a non-invasive, never contraindicated, and capable of detecting specific organ injuries initial screening method for which the sensitivity can be increased in cases of hemodynamic instability with unclear or negative ultrasound findings by supplementing with DPL [41].

Primary use of DPL can be theoretically indicated in hemodynamically unstable patients and if other diagnostic tools (ultrasound) have failed.

Computed Tomography

Key recommendation:

2.32	Recommendation	2011
GoR A	**Multi-slice spiral CT (MSCT) has high sensitivity and the highest specificity for detecting intra-abdominal injuries and therefore must be performed after abdominal trauma.**	

Explanation:

The prospective study from Liu et al. [14] compared the diagnostic predictive value of ultrasound (with screening for free fluid and organ injury), computed tomography, and DPL on 55 hemodynamically stable patients. For CT, there was a sensitivity of 97.2 % and a specificity of 94.7 %. Correspondingly good results have also been reported in more recent studies [12, 26] for the detection of hollow organ injury with CT (after administration of oral and intravenous contrast medium), which has been recognized in the past as a diagnostic weakness of CT [35]. Liu et al. also state the benefits of CT abdomen versus ultrasound and DPL in terms of the ability to reliably image the retroperitoneum. CT can easily distinguish hemoperitoneum versus fluid retention, and can localize fresh hemorrhage using contrast medium. In addition, CT abdomen (using bony windows) can also provide diagnostic imaging of the spine and pelvis (or a full body spiral according to the pattern of injury) [24]. Due to similar results previously reported above, Miller et al. and other authors recommend CT abdomen for hemodynamically stable patients regardless of the FAST ultrasound results, because CT appears to be more sensitive for the diagnosis of intra-abdominal injuries [20].

Regarding examination technicalities, Linsenmaier recommends a multi-layer spiral CT (MSCT) with regular venous contrast medium for abdominal trauma. Cuts should be at least 5-8 mm in the cranio-caudal scan direction at a pitch of 1.5. If genitourinary injury is suspected, a delayed scan (3-5 minutes after bolus administration) should be performed [13]. If possible, oral contrast can also be given for improved diagnosis of gut injuries [13, 24]. Novelline describes the administration of gastrografin via nasogastric tube first in the emergency department after insertion, shortly before transfer, and in the gantry. Normally this should allow visualization of the stomach, duodenum, and jejunum. Contrast can also be added to the rectum/sigmoid colon via rectal tube [24].

In a retrospective case-control study of 96 patients (54 consecutive patients with intestinal/mesenteric injury as well as 42 matched pairs without injury) undergoing laparotomy as well as preoperative CT (standardized with oral contrast administration via nasogastric tube in the emergency department) after abdominal trauma, Atri et al. [1] found that multilayer CT reliably detects relevant injuries to the intestines/mesentery and has a high negative predictive value. Three radiologists at varying training levels evaluated the CTs without knowledge of outcome. 38 (40 %) of the patients had surgically relevant injuries, and 58 (60 %) had either no or negligible injuries of the intestines or mesentery. Sensitivity ranged from 87-95 % for the three examiners. Only ten CTs were performed without oral contrast medium, because the patients were transferred directly to CT.

Conversely, in a retrospective study of 1082 patients (years 2001-2003), Stuhlfaut et al. concluded that multilayer CT abdomen/pelvis without contrast is sufficient to detect intestinal and mesenteric injuries requiring surgical intervention. After CT, 14 patients had suspected intestinal or mesenteric injury. Of these patients, four CTs showed pneumoperitoneum, two showed mesenteric hematoma and intestinal wall changes, and four each showed isolated mesenteric hematoma or intestinal wall thickening. Intestinal/mesenteric injuries were surgically confirmed in eleven of these patients. There were 1066 true-negative, 9 true-positive, 2 false-negative, and 5 false-positive results. The sensitivity was 82 % and the specificity was 99 %. The negative predictive value of the multilayer spiral CT (MSCT) without contrast was 99 % [40].

Although the survival advantage offered by multilayer spiral CT (MSCT) with regular venous contrast medium for rapid and reliable diagnosis of the extent of injury is clearly evident, the high radiation exposure should always be considered. For children, a good 70 % of the radiation exposure required to potentially induce thyroid malignancy is reached [32]. There is no reliable data regarding this for adult patients. Nevertheless, the potential for malignant induction must always be weighed against the indication.

In ambiguous cases (non-specific radiological findings) regarding possible intestinal/mesenteric injuries, Brofman et al. [3] recommend clinical reevaluation and repeat examination.

Experts are unanimous that the introduction of multilayer spiral CT is a step forward in spiral CT technology; in addition to better resolution, the scanning duration can be shortened considerably and motion artefacts are less disruptive [13, 24] [28, 30]. The same authors underscore the importance of using pre-programmed protocols for CT diagnosis of acute trauma (positioning, layer thickness, table advance, time and manner of contrast administration, bony/soft-tissue windows, reconstructions), since these can considerably shorten examination time. When considering concomitant injuries, some authors recommend full body MSCT after stabilization (during which abdominal ultrasound to detect/exclude free fluid should be performed). Full body MSCT enables diagnostic imaging of the skull, chest, skeletal trunk, and the extremities in a single investigation [30].

Computed tomography is the only diagnostic method for which injury scores are in place [21], on which basis treatment decisions can be made [33].
Hemodynamic status can restrict the implementation of MSCT (see the section “Influence of Hemodynamic Status on Diagnostic Studies”).

Influence of Hemodynamic Status on Diagnostic Studies

Key recommendation:

2.33	Recommendation	2011
GoR B	**For patients who are hemodynamically unstable due an intra-abdominal lesion (free fluid), emergency laparotomy should be initiated immediately. The possibility of shock from a non-abdominal cause should also be kept in mind.**	

Explanation:

The diagnostic algorithm of a patient with blunt abdominal trauma is fundamentally influenced by the vital parameters. Thus, in the early phase of treatment, the immediate evaluation and stabilization of the vital signs have the highest priority. If adequate hemodynamic stability cannot be restored despite immediate volume replacement or mass transfusion, and there is positive history and suspicion for intra-abdominal injury, Nast-Kolb et al. call for immediate emergency laparotomy [23]. Even in cases of unstable vital signs, the indication for emergency laparotomy should be supported by an abdominal ultrasound that is performed parallel to polytrauma management. This basic diagnostic workup can be performed without further time delay [14, 28]. Nast-Kolb’s working group calls for early laparotomy for patients in shock as well as in polytrauma patients (ISS $\geq$ 29) even when only a small quantity of fluid is detected. The authors justify this with the fact that a retrospective non-therapeutic laparotomy is much less traumatic and risky than a secondary operation required for an organ injury that was initially overlooked [23].

CT abdomen should only be performed when there is sufficient hemodynamic stability [22, 23, 30, 31, 42], since therapeutic interventions, for example those needed to stabilize the patient, are limited within the CT gantry [23, 30, 31, 42]. This recommendation remains fundamentally valid [11, 43, 44]; however, Hilbert et al. [9] discuss the primary use of CT even in unstable patients.

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2.6 Traumatic Brain Injury

Acute Management in the Emergency Department

Once clinical findings have been reviewed and vital functions stabilized, the polytrauma patient with traumatic brain injury generally requires diagnostic imaging, with an overall body CT scan beginning with native (no contrast) scan of the head. Because the immediate elimination of intracranial bleeding can be life-saving, delay is not justified in cases where respiratory and hemodynamic functions are stable. This applies also to the patient who was responsive at the accident scene but sedated for intubation and transport, because only CT will differentiate between a developing intracranial bleed and medication-induced unconsciousness.

Monitoring Clinical Findings

Key recommendation:

2.34	Recommendation	2011
GoR A	**Examinations of level of consciousness, with pupillary function and Glasgow Coma Scale (bilateral motor function) must be repeated at regular intervals and documented.**	

Explanation:

According to the literature, the only clinical findings with prognostic value are wide, fixed pupils [11, 23, 26] and deterioration in GCS score [11, 15, 23], both of which are correlated with poor outcomes. There are no prospective randomized controlled trials on the use of clinical findings to guide treatment. Since such studies would not be ethically justifiable, this guideline has upgraded the importance of clinical examination to grade of recommendation A, on the currently unconfirmed assumption that patient outcome can be improved by detecting life-threatening conditions with therapeutic consequences as soon as possible (see the following recommendations).

Despite various difficulties [3], the Glasgow Coma Scale (GCS) has established itself internationally as an assessment of the momentary severity of brain dysfunction. It enables standardized assessment of eye-opening, verbal and motor response. The neurological findings, documented with the time of examination, are essential for the course of further treatment. Frequent neurological checks must be carried out to detect any deterioration [11, 13].

However, the use of GCS alone risks a diagnostic gap, particularly if only total values are considered. This applies to early onset of mid-brain syndromes, which can manifest as spontaneous decerebrate rigidity, which is not recorded on GCS, or to associated injuries of the spinal cord. Thus, motor function of the extremities must be examined and recorded, with lateral differentiation of the arms and legs - whether complete, incomplete, or no paralysis is present. The presence of decorticate or decerebrate rigidity should be noted. If voluntary movements are not possible, all extremities should be examined for reactions to painful stimuli.

If the patient is conscious, then orientation, cranial nerve function, coordination, and speech must also be noted.

Vital Functions

Key recommendations:

2.35	Recommendation	2011
GoR A	**The goals should be normal oxygen, carbon dioxide, and blood pressure levels. Arterial oxygen saturation falling below 90% must be avoided.**	
2.36	**Recommendation**	**2011**
GoR A	**Unconscious patients (GCS ≤ 8) must be intubated with adequate ventilation (according to capnometry and blood gas analysis).**	
2.37	**Recommendation**	**Modified 2016**
GoR B	**In adults, the goal should be normal arterial pressure with systolic blood pressure not falling below 90 mmHg (age-adapted for children).**	

Explanation:

Due to ethical considerations, prospective randomized controlled trials examining the effects of hypotension and/or hypoxia on treatment outcomes are not justifiable. However, there are many retrospective studies [11, 25] that provide evidence of markedly worse outcomes when hypotension or hypoxia are present. The absolute priority is to eliminate all conditions associated with decreased blood pressure or blood oxygen saturation. However, aggressive therapy to increase blood pressure and oxygen saturation has not always been supported, due to adverse effects. The goals should be normal oxygen, carbon dioxide, and blood pressure levels.

Intubation is indicated for insufficient spontaneous respiration but also for unconscious patients even with adequate spontaneous breathing. Unfortunately, here as well the literature does not offer high-quality evidence that proves a clear benefit. The major argument for intubation is the efficient prevention of secondary brain injury through hypoxia. This is a threat in unconscious patients even when there is adequate spontaneous breathing, since impaired reflexes can result in aspiration. The major argument against intubation is the hypoxic injury that can occur during an unsuccessful intubation. However, it can be assumed that the conditions of the emergency department will allow immediate detection of failed intubation that can then be corrected. Ventilation is frequently required after intubation, and this must be monitored for effectiveness with capnography and blood gas analyses.

Interventions to support hemodynamic functions are the elimination of obvious bleeding (if not yet done), monitoring of blood pressure and pulse, as well as volume replacement, as described within this guideline. Specific recommendations cannot be made regarding the infusion solution to be used for volume replacement in multiply injured patients with traumatic brain injury [11].

Diagnostic Imaging

Key recommendations:

2.38	**Recommendation**	**2011**
GoR A	**In cases of polytrauma with suspected traumatic brain injury, head CT must be performed.**	
2.39	**Recommendation**	**2011**
GoR A	**In cases of neurological deterioration, (control) CT must be performed.**	
2.40	**Recommendation**	**2011**
GoR B	**For unconscious patients and/or signs of injury on the initial CT head, follow-up CT head should be performed within 8 hours.**	

Explanation:

High quality evidence regarding which situations call for cranial imaging when traumatic brain injury is suspected is not currently available in the literature. In isolated TBI, the following findings are associated with increased risk of intracranial bleed (absolute indication [16]):

- Coma,
- Decreased level of consciousness,
- Amnesia,
- Other neurological abnormalities,
- Vomiting, when it occurs soon after the impact,
- Seizure,
- Clinical signs or x-ray evidence of skull fracture,
- Suspected impression fracture and/or penetrating injuries,
- Suspected cerebrospinal fluid fistula,
- Evidence of coagulation disorder (third-party medical history, anticoagulant therapy, antiplatelet agents, incessant bleeding from superficial injuries, etc.).

Noncompulsory indications that require close clinical monitoring as an imaging alternative include:

- Unclear accident history,
- Severe headache,
- Drug or alcohol intoxication,
- Evidence of high-energy trauma. These include [1] vehicle speed > 60 km/h, severe vehicle damage, intrusion > 30 cm into the passenger compartment, time required to rescue from vehicle > 20 min, fall from $>$ 6m, vehicle roll-over trauma, pedestrian or motorcycle collision with > 30 km/h or rider thrown from motorcycle.

Since great impact force can be assumed in patients with multiple injuries, there was consensus during the development of this guideline that head CT imaging must be performed when there are symptoms of brain injury. If symptoms first occur or increase in severity during the course of treatment, control imaging is necessary, since intracranial bleeding can have delayed onset and/or increase in size. Detection of intracranial bleeding causing compression (see Chapter 3.5) requires immediate surgery.

This recommendation is based on the clinical observation that compressive intracranial bleeding can develop in patients with an initially unremarkable CT, and that initially smaller findings not requiring intervention can increase markedly in size and thus require surgery. The appearance of neurological symptoms can take several hours and/or can be masked by the intensive care treatment of unconscious patients. For this reason, there was agreement that in such cases control CT head scans should be performed at regular intervals.

Computed tomography is the gold standard of cranial imaging because of its generally rapid availability and easier examination procedure compared to magnetic resonance imaging [28]. Magnetic resonance imaging has a higher sensitivity for circumscribed tissue lesions [10]. For this reason, it is recommended particularly for patients with neurological abnormalities without pathologic CT findings.

Neuroprotective Therapy

Key recommendation:

2.41	**Recommendation**	**2011**
GoR A	**For treatment of TBI, glucocorticoid administration must be avoided.**	

Explanation:

Replacement of disordered functions (respiration, nutrient intake [17, 25], etc.) is necessary in brain-injured patients. According to current scientific understanding, the goals are to achieve homeostasis (normoxia, normotension, prevention of hyperthermia) and to avert threatening (e.g. infectious) complications. Sepsis, pneumonia, and coagulation disorders are independent predictors of poor clinical outcomes [18]. The goal of these measures is to limit secondary brain injury and to provide optimal conditions for functional regeneration of damaged but intact brain cells. This applies equally when multiple injuries are present.

There is continued debate regarding the need for antibiotic prophylaxis in frontobasal fractures with liquorrhea. However, there is no evidence for the administration of antibiotics [5, 27].

Physical thromboprophylaxis measures (e.g. compression stockings) are undisputed as means to prevent secondary complications. Regarding administration of heparin or heparin derivatives, the benefits must be weighed against the risks of increased intracranial bleeding. These drugs are not approved for brain injuries and thus, this “off-label” use must be approved by the patient or a legal representative.

Anticonvulsant therapy prevents the manifestation of epileptic seizures in the first week after trauma. However, the incidence of seizures in the early phase does not lead to worse clinical outcomes [22, 25]. Administration of anticonvulsant therapy extended more than 1-2 weeks is not associated with a reduction in late traumatic seizures [6, 22, 25].

To date, there has been no published evidence confirming the benefits derived from more extensive treatment regimens focused solely on neuroprotection. At present, no recommendation can be given for hyperbaric oxygen [4], therapeutic hypothermia [12, 21], administration of 21-aminosteroids, calcium antagonists, glutamate receptor antagonists, or tris-buffers [11,14,20,30].

The administration of glucocorticoids is no longer indicated due to a significantly increased 14-day mortality [2, 7] without improvements in clinical outcomes [8].

Therapy for Increased Intracranial Pressure

Key recommendation:

2.42	Recommendation	2011
GoR 0	**In cases where severely increased intracranial pressure is suspected, particularly with symptoms of transtentorial herniation (pupillary dilation, extensor synergy, extensor reflex to pain stimulation, progressive disorientation), the following measures can be applied:** **•Hyperventilation** **•Mannitol** **•Hypertonic saline**	

Explanation:

In cases where transtentorial herniation is suspected and there are signs of acute midbrain syndrome (pupillary dilation, decerebrate rigidity, extensor reaction to painful stimuli, progressive disorientation), hyperventilation can be initiated in the early phase after trauma [11, 25]. The reference value is 20 breaths/min in adults. Hyperventilation, used in the past because of its often impressive effects in reducing intracranial pressure, has the consequence of reduced cerebral perfusion because of induced vasoconstriction. Thus, aggressive hyperventilation involves a risk of cerebral ischemia and with it, worsening in clinical outcomes [25].

Administration of mannitol can reduce intracranial pressure (ICP) for a short time (up to one hour) [25]. Monitoring of therapy with ICP measurements is preferred [29]. When transtentorial herniation is suspected, it can be given without ICP measurement. Serum osmolarity and renal functions must also be monitored.

To date, there is no evidence for the neuroprotective effects of hypertonic saline solutions. Compared to mannitol, mortality appears somewhat less. However, the effect is based on a small case number and is not statistically significant [29].

Upper body elevation to 30° is often recommended, although this does not affect the CPP. However, extremely high ICP values are reduced.

(Analgesic) sedation itself has no ICP-lowering effect. However, it can favorably influence agitation associated with abnormal independent respiration, which can lead to ICP increases. Improved ventilation also allows better oxygenation. Although barbiturates have been recommended in previous guidelines for otherwise-uncontrollable increases in ICP [23], there is insufficient evidence for their use [19]. When barbiturates are administered, attention must be given to the negative inotropic effects, possible hypotension, and impaired neurological assessment.

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2.7 Pelvis

Importance of the Initial Clinical Evaluation of the Pelvis

Key recommendations:

2.43	**Recommendation**	**2016**
GoR A	**Acute life-threatening pelvic injury must be excluded upon patient arrival to the hospital.**	
2.44	**Recommendation**	**2016**
GoR A	**The pelvis must be physically examined for stability.**	

Explanation:

Massive pelvic bleeding in hemodynamically unstable polytrauma patient is an acute life-threatening situation. There is no alternative to immediate surgical hemostasis and accelerated blood replacement (expert opinion with strong evidence from overall national and international clinical experience). Thus, life-threatening pelvic injury must be excluded or recognized and treated within the first minutes of arrival to the emergency department [1].

Essential components of making the diagnosis include clinical examination of the pelvis, inspection for external signs of injury, abdominal ultrasound, as well as consideration of mechanism of injury. Approximately 80 % of roll-over trauma cases are associated with pelvic fractures and often lead to significant soft-tissue injuries.

The following definitions are commonly used for the most severe types of life-threatening pelvic fractures:

"In extremis" pelvic injury: massive external bleeding, e.g. in a traumatic hemipelvectomy or crush injuries after severe roll-over trauma,

Complex trauma of the pelvis and/or acetabulum: fractures/fracture-dislocations with additional peri-pelvic injuries of the soft-tissue mantle, the genitourinary system, the intestines, the great vessels and/or nerve bundles. The modification according to Pohlemann et al. [45, 47] includes bleeding from torn pelvic veins and/or the presacral plexus, which are the cause of bleeding in approximately 80 % of cases.

Traumatic hemipelvectomy: unilateral or bilateral avulsion of the bony pelvis combined with tears of the large intra-pelvic neurovascular pathways,

Pelvic-mediated hemodynamic instability (importance of the initial blood loss, e.g. > 2000 ml according to Bone [6] or > 150 ml/min according to Trunkey [65]).

If the clinical assessment suggests an "in extremis" complex pelvic trauma situation (complex trauma with hemodynamic instability), the pelvic ring must be closed as soon as possible, if not already performed in the pre-hospital setting, if necessary in a non-invasive manner e.g. with a "pelvic binder."

When multiple injuries are present, the priorities of each individual injury should be weighed against each other. If one or more injuries are equally life-threatening, only emergency pelvic stabilization takes precedence.

Primary Diagnostic Studies for Suspected Pelvic Injuries

Key recommendation:

2.45	**Recommendation**	**2016**
GoR A	**During the diagnostic survey, pelvic radiographs and/or computer tomography (CT) must be performed.**	

Explanation:

Clinical Examination:

If the patient is not "in extremis," a more detailed physical examination can be performed. This consists of a complete external inspection and palpation of the pelvic area. It includes inspection for external wounds, bruising, or hematomas, as well as internal inspection and examination of the vaginal and rectal cavities. Clinical testing of pelvic stability is increasingly debated; however, current publications have as yet insufficient evidence to change the recommendations. Shlamovitz et al. reported low sensitivity of clinical pelvic examination for the detection of a mechanically unstable pelvic ring fracture as defined [54]. In a multicenter observational study, the working group of Schweigkofler found a sensitivity of 31.6 % and specificity of 92.2 % for the detection of unstable pelvic ring fractures. The positive predictive value was 72 % and the negative predictive value was 68 % [70].

In a study from Essen, the sensitivity and specificity of the clinical pelvic exam were 44 % and 99 %, respectively. However, approximately one fifth of unstable pelvic injuries are first diagnosed using survey radiographs [40]. In contrast to Kessel et al. [34] and Their et al. [60], who question the need for emergency pelvic survey radiographs when emergency CT is available, Pehle states that they should remain part of the emergency department diagnostic protocol for polytrauma [40]. This also corresponds with the current recommendation of the ATLS® algorithm. The hemodynamic situation must be given decision-making priority. According to the data from Miller et al. [37], blood pressure not responding to volume replacement has 30 % specificity for relevant intra-pelvic bleeding. Conversely, relevant bleeding can be excluded with a high degree of certainty when blood pressure is over 90 mmHg (negative predictive value 100 %).

During the clinical examination, special attention should be given to women of child-bearing age. A pregnancy test should be performed in these patients during the diagnostic survey in the emergency department. At the same time, the possibility of miscarriage/abortion induced by the trauma should be considered in the case of vaginal bleeding and pelvic trauma. Early consultation and close cooperation with the gynecology department is indispensable in this case.

Diagnostic Imaging:

Regarding diagnostic radiographs in the emergency department, the use of whole-body CT (aka "trauma scan") is considered in many modern emergency department trauma care algorithms. Whole-body CT as the primary and possibly only diagnostic imaging in the trauma care area of the emergency department can be supplemented as needed with a preceding or subsequent anterior-posterior (AP) image. 28.6 % of surveyed DGU members reported that they perform conventional pelvic survey radiographs despite a planned trauma scan [69]. Further radiographs such as inlet/outlet or Judet views are assigned according to the particular case. Young et al. [71] state that 94 % of all pelvic fractures are correctly classified with the AP pelvis film alone. Edeiken-Monroe [19] found a success rate of 88 % for the AP pelvis x-ray. Several studies have compared CT and x-ray for diagnosis of pelvic fractures. In one retrospective study, Berg [4] detected 66 % of all pelvic fractures on the AP pelvis, and 86 % of all pelvic fractures on CT with 10 mm axial cuts. Harley [30] also found higher sensitivity for diagnostic CT, especially in detecting fractures of the sacrum and acetabulum. Resnik [48] also reported that plain x-ray misses 9 % of fractures, but noted that these fractures had no clinical relevance. Stewart [58] recommends that plain radiographs should be avoided when CT is planned. Kessel et al. [34], Their et al. [60], and Duane et al. [18] also question the need for emergency pelvic survey films when emergency CT is planned. For emergency CT, Stengel et al. [57] found a sensitivity of 86.2 % and specificity of 99.8 % for pelvic injuries after blunt trauma. However, they fear that a negative CT might have another explanation.

The increasing re-thinking of pre-hospital care as well as already improved technical equipping of rescue services (high availability of non-invasive stabilization tools such as e.g. pelvic binders) have marked influence on the results of diagnostic imaging. For example, when a pelvic binder is correctly applied, a pelvic B1 injury (pure ligamentous open book injury) can be so “concealed” that it is not detected on CT. A working group in the Emergency, Intensive, and Severely Injured Care section of the DGU (NIS) is currently working on a “clear the pelvis” algorithm with conventional radiographs/dynamic imaging under image intensification with an open pelvic binder (prior to and after CT) to address this problem.

When there is no fracture detected on x-ray, pelvic bleeding can be excluded with higher probability. Individual studies have examined the extent to which a fracture classification using conventional diagnostic x-ray can be used to assess vascular injury. Dalal et al. [15] found a significantly higher volume requirement especially in the most severe anterior-posterior pelvic fractures; however, that can also be explained by intra-abdominal injuries.

In addition, there are numbers comparing CT and angiography for the diagnosis of relevant pelvic bleeding. Pereira [41] reported accurate detection of pelvic bleeding by dynamic spiral CT in over 90 % of cases requiring embolization. Similarly, Miller [37] found a sensitivity of 60 % and specificity of 92 %. Kamaoui also found the CT pelvis examination with or without contrast helpful in identifying patients who require angiography [33].

Brown et al. [9] found relevant bleeding on subsequent angiography in 73 % of patients with pelvic fractures and contrast evidence of bleeding on CT. Conversely, close to 70 % of patients with negative CT showed a source of bleeding on angiography; thus, the relevance of bleeding must be questioned. Brasel et al. reported contrast extravasation on CT as a marker for pelvic injury severity; however, it does not mean that angiography is required. Like Brown, they found 33 % of cases with negative CT had pelvic bleeding that benefited from angiography and embolization [8].

Blackmore [5] suggested that contrast extravasation of 500 ml or more on CT indicates intra-pelvic bleeding. Analysis of 759 patients yielded highly significant association of these two with a RR of 4.8 (95% CI: 3.0-7.8). With extravasation over 500ml, then, bleeding is present in almost half of cases. When less than 200ml of extravasate is evident, there is a 95 % certainty that there is no bleeding. Sheridan [53] reports that bleeding can also be estimated on native (non-contrast) CT, because there is a correlation between hematoma development and bleeding when the size is greater than $10cm^2$.

A study from 2007 [24] investigated the sensitivity and specificity of the FAST (ultrasound) examination as an alternative to CT in patients with pelvic-mediated fractures, to help decide between emergency laparotomy and emergency angiography. Sensitivity of the FAST was 26 %, and specificity was 96 %. However, a negative result did not help with the decision regarding the need for laparotomy and/or angiography in patients with pelvic fractures [24]. CT abdomen was required for this decision, because ultrasound alone, in the eFAST context, is not considered adequate [8].

Classification of Injuries:

Bony pelvic injuries should be classified using diagnostic imaging. An exact classification of pelvic fractures is the basis for prioritized management [19]. This classification should also be undertaken as soon as possible in patients with compromised vital functions.

The AO (*Arbeitsgemeinschaft Osteosynthese*) classification is generally used, which distinguishes three fracture types:

- Stable **A** type injuries with osteoligamentous integrity of the posterior pelvic ring, intact pelvic floor; the pelvis will not displace with physiological forces,
- Rotationally unstable **B** type injuries with partially retained stability of the posterior pelvic ring,
- Translationally unstable **C** type injuries with disruption of all posterior osteoligamentous structures as well as the pelvic floor. The direction of displacement (vertical, posterior, distraction, excess rotation) plays a subordinate role. The pelvic ring is disrupted anteriorly and posteriorly, and the affected side is unstable.

The concept of a complex pelvic fracture applies for all bony injuries of the pelvis with concomitant severe peripelvic soft tissue injury e.g. hollow organ injury of the pelvis, neurovascular injuries and/or urinary tract injuries. It is also helpful to differentiate between open and closed pelvic injuries. The following pelvic injury situations would be deemed open:

- Primary open pelvic fracture: according to the typical definition with communication between the fracture site and the skin and/or the vaginal or anorectal mucosa,
- Closed pelvic fracture with packing inserted for hemostasis,
- Closed pelvic lesions with documented contamination of the retroperitoneum from an intra-abdominal injury [32].

In contrast, pelvic fractures with isolated lesions of the bladder or urethra should be considered complex injuries, but not open. Open pelvic injuries have high mortality (approximately 45 %) due to the concomitant abdominal injuries with risks of acute exsanguination as well as delayed sepsis [17].

Detection of Unstable Pelvic Fractures

Instability, particularly of the posterior pelvic ring, is accompanied by a tendency for profuse bleeding from the pre-sacral venous plexus. It is important here to distinguish between isolated mechanical instability and hemodynamic instability, although both can also occur together. Evidence of instability should promote increased awareness of the hemodynamic situation. Instability should be differentiated according to iliac wing hinging inwards or outwards, internal and external rotation. In cases of translational instability, there can be craniocaudal instability in the horizontal plane or anterior-posterior instability in the sagittal plane. In addition to the increased bleeding risk, instability can lead to further complications such as thrombosis and secondary nerve, vascular, and organ injuries. The latter can be primary injuries and must be excluded during the primary diagnostic survey in unstable pelvic injuries. Pelvic instability should be managed with early surgery. Depending on patient condition, this can be a quick damage control procedure, or direct definitive treatment (more time intensive). There is consensus, however, that mechanical stabilization (regardless of method) has highest priority and should ideally be performed at the scene of the accident. Hemostasis has a similarly high priority and should be implemented according to the available alternatives.

Signs of pelvic instability can be identified on diagnostic imaging. These include, for example, widening of the public symphysis or the SI joints. Displacement of the iliac wings horizontally or vertically should also be considered a sign of instability. It should be kept in mind that displacement is frequently much greater at the time of trauma than at the time of diagnosis. Thus, a fracture of the transverse process of the L5 vertebra should be evaluated as a sign of instability if there is concomitant pelvic injury, even if there is no iliac wing displacement. It should also be kept in mind that a correctly placed pelvic girdle or pelvic binder can mask pelvic instability.

The vector of pelvic instability is important for classification. If there is rotational instability only of the pelvis over the vertical axis of the posterior pelvic ring, this is a Group B injury. If there is translational instability in the vertical or horizontal plane, it is a Group C injury.

Emergency Stabilization of the Pelvis

Key recommendation:

2.46	**Recommendation**	**Modified 2016**
GoR A	**In cases of an unstable pelvis and hemodynamic instability, emergency mechanical stabilization must be carried out.**	

Explanation:

Only simple and rapid procedures are suitable for emergency stabilization of the pelvis. Use of a sheet or pneumatic or other industrial pelvic girdles is clearly inferior to an anterior external fixator and the pelvic C-clamp in terms of mechanical stability. Nevertheless, both procedures are effective as emergency measures at least temporarily in an urgent situation [16]. On the other hand, mechanical stability of the Ganz C-clamp or external fixator are dependent on fracture type. The exact timeline of the injury must be observed. Early stabilization with a cloth sling or a pelvic girdle (pelvic binder) can be better for patient outcome than a later stabilization with a supra-acetabular fixator and pelvic clamp.

There is continued debate whether the anterior external fixator (supra-acetabular) or the pelvic C-clamp should be used. For unstable pelvic fractures type C (AO or CCF), the pelvic C-clamp is preferred over the anterior fixator as evidenced by biomechanical studies [46]. For unstable type B injuries, there were no noteworthy differences between the two. There have been no studies on the question of which emergency stabilization technique has the best effect on hemostasis [10, 14].

Overall, the pelvic C-clamp is used less often, since it is a less definitive solution compared to the external fixator and has special contraindications. For example, trans-iliac fractures are a contraindication, because with compression, the spine of the clamp could pass through the fracture and result in lesser pelvic organ injury. On the other hand, reliable stabilization with an external fixator is not always possible when there is posterior instability. Siegmeth et al. [55] theorize that an external fixator is sufficient for instability of the anterior pelvic ring, but that injuries to the posterior pelvic ring need additional compression in an emergency. Trafton et al. called for the same already in the late 1980s [64]. Studies of a commercial pelvic girdle (non-invasive pelvic stabilization) have yielded contradictory results regarding reductions in mortality, pRBC transfusions, and duration of trauma-related hospital admission. Although Croce [13] reported benefits of the pelvic girdle in his study, these findings were not confirmed by Ghaemmaghami et al. [25]. One important change, however, is that in recent years, the use of pelvic girdles and other non-invasive external stabilization techniques has increasingly established itself in the pre-hospital setting. The consequence of this is that effective emergency stabilization is begun markedly earlier. The initiation of non-invasive stabilization occurs generally based on accident kinematics and can stabilize and manage the patient with pelvic bleeding much sooner.

The widespread use of pelvic girdles has also changed emergency stabilization within the trauma care area of the emergency department. In a retrospective study, Pizanis et al. [44] investigated the effects of three different emergency stabilization techniques mainly on mortality. A time advantage was identified for the use of cloth slings and pelvic binders. The sequential procedure used in current practice, with pre-hospital application of a pelvic girdle followed by in-hospital change to a C-clamp when necessary was discussed, but the effects could not be analyzed based on the study design. Commercial pelvic binders appear to have benefits over cloth slings. This is because of the implementation, particularly in the positioning of the device. Similar to Bonner et al. [6], the unpublished results of a retrospective analysis of over 500 trauma scans with some 200 applied pelvic girdles by Schweigkofler from Frankfurt found that a correct position within a corridor ± 5 cm around the ideal position was reached in only 62 % of cases.

The data regarding frequency of use of pelvic C-clamps, pelvic binders, and cloth slings showed discrepancies. In a survey on emergency management of the pelvis, Wohlrath et al. [69] found that a pelvic C-clamp was used in only 47.7 % of cases as an emergency stabilization device, while it was used in 69 % of cases in the Pizanis et al. [44] study. Today, the pelvic C-clamp is used less often within the emergency department, but increasingly in the "safe" operating room environment [44].

Procedures for Hemodynamic Instability Associated with Pelvic Fractures

Key recommendation:

2.47	Recommendation	Modified 2016
GoR B	**In cases of persistent bleeding, surgical hemostasis and/or selective angiography with angioembolization should be performed.**	

Explanation:

Unstable pelvic fractures often lead to profuse bleeding, depending on the degree of posterior pelvic ring displacement. If an unstable pelvic fracture is diagnosed in combination with hemodynamic instability, the pelvic fracture should be considered a possible cause of the hemodynamic instability. Except in cases of severe pelvic roll-over trauma, emergency stabilization of the pelvis using the methods already described here in combination with volume replacement infusion therapy can lead to persistent hemodynamic stabilization, so that the need for surgical hemostasis can be reevaluated. The ATLS©-compliant classification as "responder" and "non-responder" can be a useful decision aid in this case.

If the patient continues to be a "non-responder," with persistent hemodynamic instability despite these measures, additional measures must be undertaken. There are basically two possibilities: surgical tamponade and embolization. When selecting one of these procedures, it should be noted that only arterial bleeding can be embolized, and that this is estimated to account for only 10-20 % of cases of bleeding in severe pelvic injuries. The remaining 80 % are of venous origin [38].

In view of this, surgical tamponade of the lesser pelvis appears reasonable and, in the German-speaking world at least, is considered the method of first choice in such cases ([20], prospective study with 20 patients). Similarly, in a prospective study of 150 patients, Cook [11] found an advantage for rapid mechanical stabilization followed by surgical hemostasis or tamponade. Pohlemann et al. [45] made similar recommendations based on a prospective study of 19 patients, and Bosch [7] after a retrospective analysis of 132 patients. However, prior mechanical stabilization of the pelvic ring is imperative.

At the same time, embolization must also be considered. Miller [37] considers angiography and embolization even more valuable than mechanical stabilization. Operative stabilization merely delays efficient hemostasis and also represents avoidable surgical trauma. According to Hagiwara, patients with hypotension and "partial responders" receiving two liters of fluid after blunt abdominal trauma and injury to the pelvis and/or liver and/or spleen, etc. benefit from angiography and subsequent embolization. After embolization, volume requirements decreased significantly and the shock index normalized [28, 29].

In a retrospective study for the years 2007-2012, Marzi investigated 173 severely injured patients with pelvic ring fractures. The following algorithm was applied: angioembolization as hemostasis was used only in hemodynamically stable "responder" patients. In contrast, hemodynamically unstable patients underwent mechanical and surgical hemostasis in the operating room as soon as possible prior to angioembolization [36].

Agolini [2] writes that only a small percentage of patients with pelvic fractures require embolization. When applied, however, it can be close to 100 % effective. Patient age, time of embolization, and the extent of initial hemodynamic instability influence survival rate; for example, angiography performed three hours after trauma resulted in 75 % mortality versus 14 % when it was performed less than three hours after the accident. Pieri et al. found 100 % effectiveness of emergency angiography with embolization in pelvic-mediated hemodynamic instability and bleeding from the obturator as well as the gluteal arteries [43]. Tottermann found significant arterial bleeding from the internal iliac artery in 2.5 % of patients with pelvic injuries. With an all-cause mortality of 16 % in the patient population, he identified an inverse proportionality between age and survival probability [62].

Panetta [39] postulated that early embolization with a range of 1-5.5 hours (average 2.5 hours), but found no correlation between time of procedure and mortality. Outcome reports identified no benefits for embolization, with success rates of approximately 50 % when performed within six hours after the accident [41]. The groups of Kimbrell [35] and Velmahos [66] are in favor of liberal use of embolization for abdominal and pelvic injuries with confirmed arterial bleeding even in patients without initial signs of hemodynamic instability.

Gourlay et al. [26] describe angiography as the gold standard for arterial bleeding in pelvic fractures. A special subpopulation of approximately 7-8 % even needed follow up angiography because of persistent hemodynamic instability. A study by Shapiro [52] gave indication for re-angiography as persistent shock symptoms (SBP $<$ 90 mmHg), lack of other intra-abdominal injuries, and sustained base excess $<$ -10 for more than six hours after admission. In the subsequent re-angiography, there was pelvic-mediated bleeding in 97 % of cases.

In a study by Fangio, some 10 % of patients with pelvic injuries were hemodynamically unstable. The subsequent angiography was successful in 96 % of cases. Angiography enabled the diagnosis and treatment of non-pelvic bleeding in 15 % of cases. This decreased the rate of false positive emergency laparotomy procedures [23]. Sadri et al. [49] also discovered that a specific subgroup of pelvic injuries (approximately 9 %) with persistent volume requirements benefited from emergency mechanical C-clamp stabilization of the pelvic ring and subsequent angiography/embolization.

On the other hand, Perez [42] also considers embolization a fundamentally reliable procedure, but sees a need for clarification of the parameters defining indications and effectiveness for use. Salim et al. reported the following parameters with significant predictive values to identify the group of patients who benefit from angioembolization: SI joint disruption, female gender, and persistent hypotension [50].

According to Euler [21], interventional radiological procedures like embolization or balloon catheter occlusion are more important in the later, post-primary treatment phase and not during polytrauma management. Only 3-5 % of hemodynamically unstable patients with pelvic injury require and/or benefit from embolization [3, 22, 38].

As characterized above, there are divergent opinions in the literature. These differences can be explained to some extent by the considerable differences in patient collectives and injury severity.

No definitive recommendation can be given due to the lack of high quality evidence for both packing and embolization. Rather, it is crucial that a stabilizing intervention must be applied, since unnecessary delay worsens patient outcome. In the end, surgical hemostasis (packing and external stabilization) and angioembolization are not competing, but complementary procedures with different foci. The preferred method will also certainly depend on local circumstances. In addition to the availability of embolization, particular consideration should be given to the fact that no other measures can be performed in parallel for the patient during the procedure. Finally, there is the need for strict time management, which must be adhered to in any case.

Data from the Pelvic Registry III of the DGU showed an increase in emergency angiography procedures performed in Germany from approximately 2 % to 4 %. In 2008, Westhoff recommended early clinical integration of interventional emergency embolization for pelvic fractures in cases when the appropriate infrastructure is in place [68]. Until 2007, the Anglo-American literature in particular seemed to emphasize the angiography approach. The results of the following two studies from 2007 might be interpreted as the beginning of a paradigm shift.

Tottermann reported a significant blood pressure increase after surgical packing. In the subsequent angiography, there was still evidence of arterial bleeding in 80 % of cases, so that he suggests a stepwise approach with surgical packing followed by embolization [63]. The study of Cothren found a significant reduction in the need for packed red blood cell (pRBC) transfusions within 24 hours of hospital admission for the patients receiving pelvic packing only compared to the angiography group (approximately 12 versus 6 units pRBCs; [12]). Sufficient training of operating personnel is essential to adequate patient stabilization with surgical packing. Packing is a sufficient method of hemostasis only when surgeons are adequately trained in the method.

In 2008, Vorbeek called for the adaptation of current treatment protocols in the treatment of severely injured patients with pelvic fractures, to stop pelvic bleeding and particularly to avoid non-therapeutic and/or false positive laparotomies [67].

A potential algorithm must account for hemodynamic status and source of bleeding:

(a) Mechanical stabilization/packing (venous/bony bleeding),
(b) Mechanical stabilization (also non-invasive) and angioembolization (arterial bleeding),
(c) Mechanical stabilization/packing + secondary addition of angioembolization if needed (persistent hemodynamic instability after packing/stabilization).

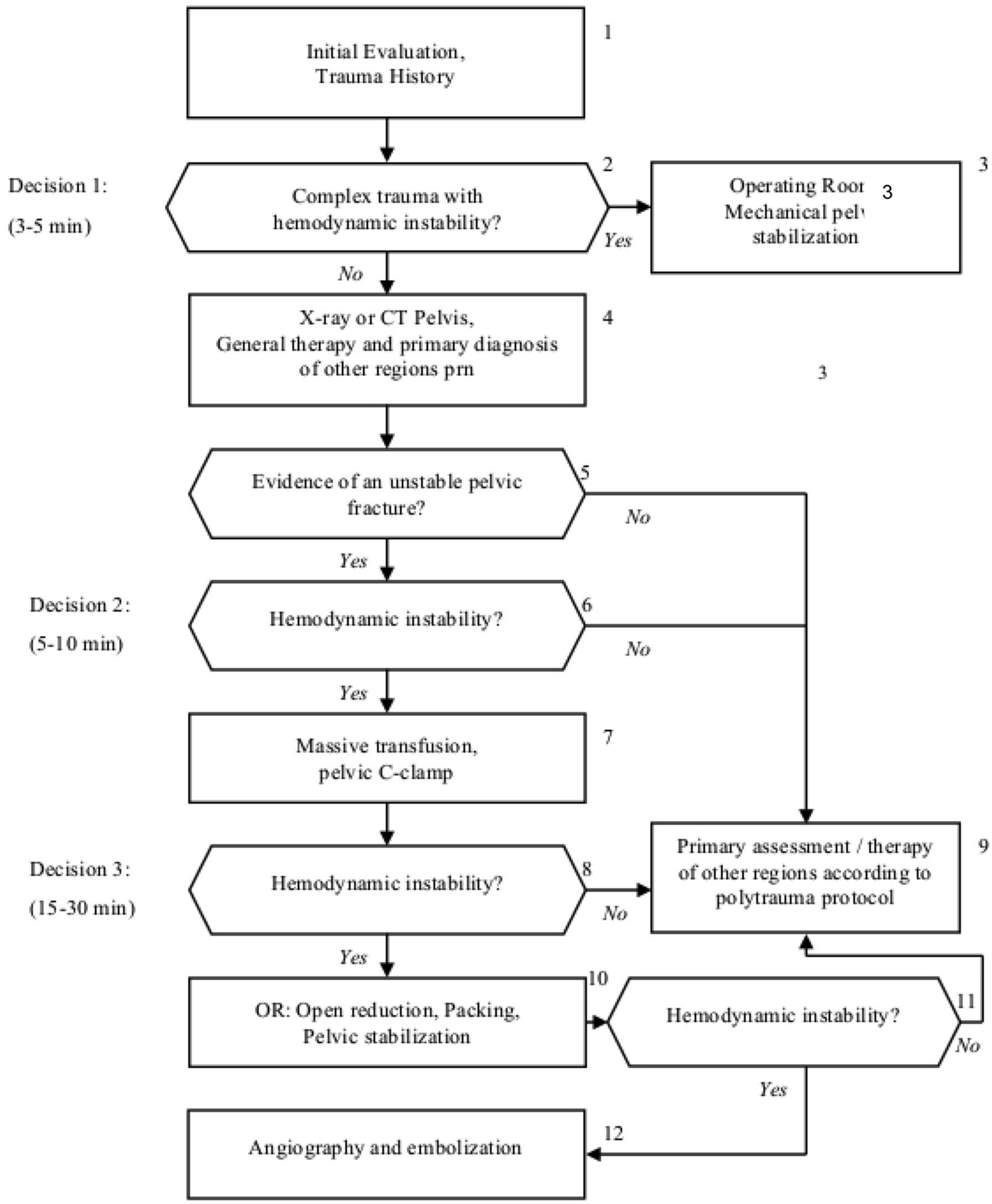
In the end, there are no clinical studies offering the corresponding data required for decision making for e.g. the stepwise algorithm given above. The comparison of angioembolization and surgical hemostasis alone is not appropriate to the clinical picture (bleeding problems in pelvic fractures).

In a study based on registry data of the "Pelvic Registry" from 2004 to 2009, Hauschild et al. [31] compared angioembolization and packing. However, since angioembolization was not available in all participating clinics, group comparison is not quite sufficient. The data give no information regarding the time course of therapy nor the classification of arterial or venous sources of bleeding.

Specific Considerations for Pelvic Fractures in Geriatric or Pediatric Patients

Severe pelvic injuries are more life-threatening in children and the elderly than for adults in middle age, and thus, require even more rapid and effective management. The physiologic compensatory mechanisms of circulation and hemostasis are markedly less. The time pressure, under which decisions must be made, grows. In children, the first challenge is to recognize the threat to vital functions. Circulatory decompensation does not emerge gradually, but appears suddenly, because pediatric physiology offers few compensation possibilities. Emergency stabilization of the pelvis can be performed with simple compression bilaterally, manually if needed. There are no large series of studies on pediatric pelvic fractures available in the literature. The works of Torode [61], Silber [56], and Tarman [59] all report that treatment guidelines do not differ significantly from those of adults. There are no reports of the use of a pelvic C-clamp in children. The need for volume replacement and surgical hemostasis are applicable just as in adults. Regarding diagnostic imaging, magnetic resonance imaging (MRI) has the advantage versus CT that it depicts non-ossified structures and thus, enables multiplanar characterization of a pelvic injury. Plain x-rays have a significantly weaker predictive value than computed tomography as a diagnostic study of bony pelvic structures and can be used as a complement or completely omitted according to Guillamondegui et al. [27]. Only in hemodynamically unstable patients are the conventional pelvic survey films still indicated, during the initial trauma survey. The elasticity of the pediatric pelvis requires special consideration, because a complete re-assembly of the pelvic skeleton can occur despite severe roll-over trauma. In 20 % of pediatric complex pelvic injuries, a normal pelvic skeleton is visualized on the plain x-rays as well as on CT.

Figure 4: Treatment Algorithm of Complex Pelvic Trauma [51]



In spite of the current level of data, a treatment algorithm can be developed from the various and sometimes very weak grades of evidence, which can then be changed according to local logistical conditions. A so-called "Clear the Pelvis" algorithm must still be developed and scientifically evaluated. The earlier non-invasive, and sometimes prophylactic, pelvic stabilization with a pelvic girdle through exclusion of relevant pelvic injury occurs, just like the sequential use of diagnostic radiology (whole-body CT, pelvic survey views AP, dynamic views with image intensification), has a special meaning.

The evidence table for this chapter is found on page 179 of the guideline report.

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2.8 Genitourinary Tract

Primary Clinical Assessment

Key recommendation:

2.48	**Recommendation**	**2011**
GoR B	**The primary diagnostic survey should include inspection of the external urethral meatus and the transurethral catheter (if already inserted) for blood.**	

Explanation:

Gross hematuria is the classic cardinal symptom for injuries to the kidney, bladder, and/or urethra. In contrast, ureter injuries are clinically undetectable in almost 50 % of cases [11]. Thus, the urinary catheter and the urethral meatus should be examined for blood during the primary survey of the undressed patient [33]. Blood at the urethral meatus should be distinguished from hematuria, as the two have different diagnostic implications.

Key recommendation:

2.49	Recommendation	2011
GoR B	**The flanks, abdomen, perineum, and external genitalia should be examined for hematomas, ecchymoses, and external injuries.**	

Explanation:

Because the external physical examination can be rapidly and easily performed, it should be carried out in all polytrauma patients even though it offers only low diagnostic value [12]. The examination includes inspection for external signs of injury (hematoma, abrasions, swelling, etc.) of the flanks, perineum, groin, and external genitalia.

The value of a digital rectal exam is still debated, since it seldom reveals pathology [33]. However, a digital rectal exam should still be performed to assess sphincter tone in spinal cord injuries as well as in cases where there is blood at the urethral meatus or when a pelvic fracture suggests urethral injury [33]. A prostate that is non-palpable, displaced or surrounded by hematoma also offers clinically valuable information, suggesting prostato-membranous tear [33].

Responsive patients can be questioned regarding details of the accident and pain associated with genitourinary injuries. Abdominal pain can give non-specific indications of intra-abdominal injuries [13, 16, 18]. In addition, bladder rupture is specifically suggested when a patient recounts an urge to urinate prior to the trauma that is no longer present afterwards (without evidence of neurologic lesions) [19], or when the patient tries to urinate post-trauma without success [22].

The following external signs of injury can suggest associated urologic injuries: hematoma, swelling, and abrasions of the flanks, perineum, groin, and external genitalia.
In the studies of Cotton et al. and Allen et al., ecchymoses and abrasions of the abdomen correlated with intra-abdominal injuries [3, 29]. Hematoma of the penile shaft or perineal butterfly hematoma suggests anterior urethral injury [3, 29].
If the patient feels the urge to urinate prior to the trauma and no longer senses it after the trauma, this suggests bladder rupture, when there is no evidence of neurologic lesions [33]. A failed attempt at micturition after trauma is also suggestive of a bladder rupture [33].

Key recommendation:

2.50	Recommendation	2011
GoR B	**In cases of hemodynamic instability that precludes further primary diagnostic examination, and in cases when it is impossible to place a transurethral bladder catheter, a suprapubic urinary catheter should be placed percutaneously or during laparotomy (with concomitant exploration).**	

Explanation:

In cases of complete urethral rupture, a false passage can be created with the insertion of a transurethral catheter [76]. An existing urethral injury can also be aggravated by transurethral catheter insertion [76]. Thus, in patients with clinical signs of urethral injury, transurethral catheterization can be carried out in the emergency department with x-ray control (e.g. retrograde urethrogram) to better monitor elimination. This is only contraindicated in very unstable patients in whom catheter insertion would represent an unnecessary delay, and for situations that are unclear even with radiographic control [76].

In cases of hemodynamic instability, where further diagnostic assessment is not possible due to time concerns and where laparotomy is to be performed for these reasons, a suprapubic catheter should be placed during this procedure that can later be used for diagnostic purposes [26]. Urinalysis and serum creatinine measurement should be performed [33]. A dipstick urine test should be carried out to detect hematuria. Compared to microscopic examination, the dipstick has over 95 % sensitivity and specificity [23, 24, 37]. The advantage of the dipstick test is that results are available in under 10 minutes. It is also helpful to provide evidence of bacteriuria, something often present in the elderly that can be particularly problematic in combination with a urinary tract injury [33].

Need for Diagnostic Imaging

Key recommendation:

2.51	Recommendation	2011
GoR B	**All patients with hematuria, blood at the urethral meatus, dysuria, failed catheterization, or other historical evidence (local hematoma, concomitant injuries, mechanism of injury) have increased risk of urogenital injuries and should undergo a targeted diagnostic work-up of the kidneys and/or the efferent urinary tract.**	

Explanation:

Even though simultaneous injuries of the upper and lower urinary tracts occur in only 0.6 % of patients, a complete urological workup is generally carried out in all patients with corresponding signs, since this normally is performed as CT for confirmed micro or gross hematuria and includes the entire urinary system [55, 63, 67].
While gross hematuria is pathognomonic for genitourinary injuries, microhematuria is borderline. Currently, however, it is generally accepted that diagnostic assessment should continue only if there is other evidence of injury [45, 58].

Renal trauma is classified according to mechanism of injury, blunt or penetrating. While in rural areas, blunt trauma accounts for 90-95 % of renal injuries (horse kicks, accidents), the proportion of penetrating injuries climbs to 20 % in urban areas [44, 69].

Blunt renal trauma includes car, pedestrian, and sport accidents as well as falls. In car accidents, acceleration trauma usually occurs through seat belts or steering wheels [50, 76]. The widespread use of airbags has led to a 45-53 % reduction in renal trauma incidence [76]. Direct blunt forces on the flanks or the abdomen during sports accidents are another frequent cause of blunt renal trauma [14]. Sudden deceleration trauma through accidents can be accompanied by renal contusions, lacerations, or avulsion of the renal parenchyma [76].

Injury to the renal hilum occurs in 5 % of abdominal trauma cases [17]. Renal artery occlusion is frequently associated with deceleration trauma [17, 76]. Pathophysiologically, traction of the vascular trunk leads to tearing of the intima, and the resulting hemorrhage to thrombosis [17].

Penetrating renal injuries are mostly caused by gunshot or stabbing and are generally more severe than blunt trauma [76]. Due to the kinetics, projectiles destroy more parenchyma and are associated with multiple organ injuries [61]. The pattern of injury is characterized by rupture of the parenchyma, vascular trunk, or the renal pelvic calices [76].

The most commonly used classification system is the AAST (American Association for the Surgery of Trauma) Classification [57]. Renal trauma is classified in five grades from I to V (Table 12). The classification is made based on computed tomography (CT) of the abdomen or through direct surgical exploration. Validation with magnetic resonance imaging is also possible; however, due to the time requirements it is impractical in the emergency department trauma care phase [30]. The classification is an independent variable to predict the need for surgical exploration or nephrectomy, the morbidity after blunt or penetrating injuries, and the mortality after blunt trauma [51, 71, 73].

Table 12: Grades of Renal Trauma according to Moore [57] and Buckley [20]

Grade	Anatomic Pathology, Radiological Findings
I	Renal contusion or subcapsular hematoma, non-expanding, no parenchymal lesion
II	Non-expanding peri-renal hematoma, cortical parenchymal tear < 1 cm depth, no extravasation
III	Cortical parenchymal tear > 1 cm depth, no extravasation
IV	Parenchymal injury through the corticomedullary border into the collecting system, shattering of the parenchyma or arterial or venous vascular injury of a segment with hematoma
V	Vascular injury of the renal hilum

In 2011, the American Association for the Surgery of Trauma amended the classification from 1989 [20]. Stages I-III remained unchanged. The extensive parenchymal injury with shattering from Stage V was moved to Stage IV, and Stage V kept only injuries (laceration, avulsion, or thrombosis) of the renal hilum [20]. Potential indicators of severe renal injuries are rapid deceleration trauma and direct, blunt impacts to the flank [20, 33, 76].

During the pre-hospital phase, possible pre-existing renal disease (single kidney, renal insufficiency) should be evaluated. Patients with a single kidney represent a particular risk group [2, 21]. In addition, anatomical variants or congenital anomalies (ureteropelvic junction obstruction, renal cysts, renal calculi) can make minimal kidney trauma more severe [72]. Sebastia et al. quantify the incidence of normal variants as up to 22 percent [72].

Hemodynamic stability is the primary criterion for the management of all renal trauma [58].

Penetrating trauma of the posterior thorax, the flank, and the upper abdomen as well as blunt impact to the back, flank, upper abdomen and lower thorax can also suggest renal trauma [76].

Diagnosis of ureter injuries is challenging. In cases of penetrating trauma, it is generally made during laparotomy; in blunt trauma, it is often delayed [15, 52].

External ureter trauma is mostly associated with severe abdominal and pelvic injuries [74]. While penetrating trauma is often associated with vascular or intestinal injuries, blunt trauma leads to injuries of the bony pelvis and lumbar spine [74].

Hematuria is an unclear indicator of ureter injury. In case of a non-peristaltic, partially or completely severed ureter, hematuria might not be present [36]. It is crucial to consider the chance of ureter injury in penetrating or blunt abdominal injuries [70].

Armenakas et al. found that symptoms and clinical considerations described above were not delayed in 93 percent of all external ureter injuries and could be detected intraoperatively in 57 % [6].

All symptoms (fever, unclear leukocytosis, peritoneal irritation) should lead to a rapid diagnosis with CT and CT-urogram. If a ureteral injury is not initially detected, retrograde ureteropyelography is the diagnostic study of choice after 48 hours [70].

Patients with traumatically-induced urinary bladder injuries usually require interdisciplinary management, since both blunt and penetrating injuries are often associated with abdominal injuries or pelvic fractures. The distinction between intra and extra-peritoneal urinary bladder injuries, as well as detection of associated injuries of the bladder neck or the proximal urethra, is important. Thus, the initial assessment for precise evaluation of injuries plays an important role.

Motor vehicle accidents are the leading cause (90 %) for blunt bladder injuries [9, 40]. Approximately 70 % of patients with blunt bladder injuries have concomitant pelvic fractures (especially pelvic ring fractures, symphysis ruptures, pelvic rami fractures) and approximately 44 % of patients have at least one intra-abdominal injury [9, 32, 40]. Penetrating bladder injuries from gunshot wounds or impalement injuries are rare [28]. Extra-peritoneal bladder ruptures are more common than intraperitoneal, and they are mostly associated with pelvic fractures, caused by displacement of the pelvic ring. Intraperitoneal bladder injuries are caused by suddenly increased intra-abdominal pressure, kicks to the genitalia or in the lower abdomen. A full bladder thus increases the risk for intraperitoneal bladder rupture [40].

Injuries to the urethra have been classified by the American Association for Surgery of Trauma in five grades regarding the continuity of the urethral circumference (modified by Moore et al. [56]) as follows:

- I Contusion (incomplete tear of the urethral circumference with evidence for blood at the urethral meatus or evidence of extravasation on retrograde urethrogram (RUG)
- II Elongation injury of the urethra (elongation of the urethra with intact urethral circumference, without extravasation on RUG)
- III Partial rupture of the urethra with complete disruption of the anterior/posterior urethral circumference (with evidence of urethral extravasation and visualization of the bladder)
- IV Complete rupture of the urethra, < 2 cm urethral separation (with evidence of urethral extravasation but without visualization of the bladder)
- V Complete rupture of the urethra, ≥ 2 cm urethral separation or injury extending into the prostate or vagina

90 % of urethral injuries occur with blunt external injury patterns such as traffic accidents, impact injuries (straddle trauma, e.g. impact against bicycle handlebars) or direct injuries to the perineum [54]. They generally concern the front aspect of the anterior urethra (compression of the bulbar urethra between a blunt object and the pelvis) [54]. Pelvic fracture-associated urethral injuries (PFUI) are usually caused by shearing injuries (distraction forces), in which pelvic bone fragments contact the urethra and thus, the anterior (80 %) section is more often affected than the posterior section (proximal to the sphincter) [60].

Penetrating or open injuries resulting from gunshot wounds, dog bites, or impalement injuries affect the anterior urethra (penile and bulbar) more than the posterior urethra [54].

PFUI concerns the anterior urethra (distal to the sphincter) in up to 80 % of cases and is the most common urethral injury after iatrogenic injury; 19 % of males and 6 % of females with pelvic fractures have associated urethral injuries [76]. PFUI occurs most commonly in combination with unstable pelvic fractures with diastasis of the sacroiliac joints and/or the public symphysis [60].

Key recommendation:

2.52	**Recommendation**	**2011**
GoR B	**Further diagnostic imaging of the efferent urinary tract should be performed when one or more of the following criteria are met: hematuria, bleeding from the urethral meatus or the vagina, dysuria, and local hematoma.**	

Explanation:

Numerous studies have found that bladder ruptures are associated with pelvic fractures in approximately 70 % of cases [9, 40]. Hochberg and Stone found a direct correlation between the number of fractured pubic rami (1, 2-3, 4) and the frequency of bladder ruptures (4%, 12%, 40%) [41]. Aihara et al. also found that disruption of the pubic symphysis or sacroiliac joint is present in 75 % of bladder ruptures after blunt trauma [1]. Nevertheless, bladder rupture cannot be deduced from the presence of complex pelvic fracture, as only 20 % (positive predictive value) of patients with symphysis and sacroiliac joint disruption have bladder rupture [1].

The close correlation between pelvic fractures and urethral injuries is well documented. However, the severity of the injury plays a big part [4, 5, 10, 75]. Koraitim et al. and Aihara et al. have consistently found that pubic rami fractures increase the risk of urethral injuries, but the risk increases enormously in the presence of complex pelvic fractures (type C) [1, 47, 48]. Aihara et al. emphasize that fractures of the inferior pubic rami in particular suggest urethral injury [1]. In a series of 200 patients with pelvic fractures, Palmer et al. found that 26 of 27 patients with urological lesions had fractures of the anterior and posterior rings [62]. The association is less marked in women because of the shorter urethra with less connective-tissue tethering [10, 78]. Urethral injuries in women are most often accompanied by bleeding vaginal injuries [78].

The classic combination of pelvic fracture and gross hematuria enables a diagnosis of bladder and/or urethral injury with a high degree of certainty [41, 62]. Of 719 patients with blunt pelvic/abdominal trauma, Rehm et al. found all 21 cases of bladder injuries through hematuria, 17 of whom had gross hematuria [66]. Morey et al. also reported that 85 % of their patients with pelvic fractures and concomitant bladder rupture had gross hematuria [59]. In the study of Palmer et al., this number was ten of eleven patients, and in Hsieh et al. it was 48 of 51 patients [42, 62]. A gap of the pubic symphysis and separation of the sacroiliac joint doubled the risk for bladder injury in the study by Aihara et al. [1]. However, even without evidence of pelvic fracture, patients with gross hematuria or blood at the urethral meatus must be assumed to have an injury of the efferent urinary tract [58, 76].

The distinction between hematuria and blood at the urethral meatus can be helpful to distinguish bladder and urethral injuries. Morey et al. reported that all 53 patients with bladder ruptures had hematuria, but also that blood at the urethral meatus, present in all six cases, correctly indicated an associated urethral injury [59].

The current body of evidence indicates clearly that a lack of hematuria and corresponding exclusion of pelvic injury exclude relevant injury of the bladder or urethra [58, 62]. Assessment in cases of pelvic fracture are somewhat more difficult [41]. Hochberg and Stone found that here, a urological injury remains unlikely as long as the pelvic fracture does not involve the pubic rami [41].

Diagnostic Imaging of the Kidneys and Ureters

Key recommendation:

2.53	Recommendation	2011
GoR B	CT with contrast should be performed for suspected kidney injuries.	

Explanation:

Computed tomography with contrast is available almost nationwide and enables rapid and adequate detection and staging of significant kidney injuries [58]. Even in pediatric polytrauma patients, CT can be performed immediately following the emergency department trauma care phase [58]. Current developments of modern dual-source CT scanners with minimal tube voltage (70-100 kV) enable perfusion measurement and iterative image reconstruction not only with lower radiation dose, but also decreased amounts of contrast medium [27, 35, 80]. To date, this new generation of dual-source CT scanners have mainly been used for CT angiography and thoracic imaging, but because of the short examination time, it is also useful for emergency department diagnostic assessment of polytrauma patients [27].

Although intravenous pyelography is a sensitive method for the diagnosis of renal trauma, it has currently been largely supplanted by the use of CT [58, 76]. Therefore, current guidelines recommend its use only in centers without available CT [8, 58, 76]. The main reasons for this are time delay as well as the decreased image quality. Validity is limited to extravasation and evidence of a mute kidney, which is generally a sign of extensive renal trauma or an injury to the renal vascular hilum [76]. Extravasation suggests a high-grade renal injury with tearing of the capsule as well as the parenchyma and involvement of the renal pelvis [76].

Ultrasound offers a rapid, non-invasive, cheap, and radiation-free option to detect retroperitoneal fluid collections [68]. The disadvantage is the high dependence on examiner proficiency and patient positioning [68].

Renal lacerations can be detected on ultrasound, but there is less accuracy regarding depth and expansion [58]. Statements regarding urinary extravasation or leakage are also difficult to make [58]. On the other hand, ultrasound monitoring of parenchymal lesions, retroperitoneal hematomas, or urinomas are possible within the intensive care setting [18]. Contrast-enhanced ultrasound (CEUS) has greater sensitivity than conventional ultrasound and can be useful in blunt trauma [38]. The patient must, however, be hemodynamically stable [58].

Angiography is indicated in stable patients who are determined as eligible for interventional bleeding control after CT diagnosis [34]. Overall, angiography is less specific, more time-intensive, and more invasive than CT; however, it is more specific in terms of localization and assessment of the severity of vascular injuries [76].

Diagnostic indications are lacerations, extravasation, and assessment of renal hilar vessels as well as unclear findings on CT [76]. In addition, causes of a non-visualized kidney (complete avulsion of the renal hilar vessels, renal artery thrombosis, vascular spasm after contusion) can be evaluated on angiography [76].

Due to long examination time, cost effectiveness, and the limited access to patients during the examination, magnetic resonance imaging is suitable as a primary diagnostic imaging procedure to assess renal trauma only when there is a contrast allergy or when CT is not available [53]. The domain for MRI is in monitoring after renal trauma and particularly in the assessment of lacerations and individual fragments [31, 76].

Thus, for primary trauma diagnostic assessments in the emergency department, the importance of CT has gradually increased over recent years [71]. Consequently, CT has become the current standard investigation during the initial emergency department trauma care phase [76].

Diagnostic Imaging of the Lower Urinary Tract

Key recommendations:

2.54	**Recommendation**	**2011**
GoR B	**If the priority of care allows, retrograde urethrography and a cystogram should be carried out in patients with clinical evidence suggesting a urethral lesion.**	
2.55	**Recommendation**	**2011**
GoR B	**If the priority of care allows, a retrograde cystogram should be carried out in patients with clinical evidence suggesting a bladder injury.**	

Explanation:

The main symptom of urethral injury is gross hematuria (> 95 % of patients) [9, 40]. However, a lack of gross hematuria does not exclude bladder injury [7].

Other symptoms suggesting bladder injury could be: abdominal guarding (up to 97 %), inability to urinate, or abdominal tension with urinary ascites [28, 40, 77]. Furthermore, swelling of the perineum, the scrotum, or tension along the anterior abdominal wall because of urine extravasation are observed. Increased serum creatinine and urea levels, caused by peritoneal resorption, can also be present in intraperitoneal bladder rupture.

In cases of urinary retention and/or blood at the urethral meatus, an associated injury of the urethra must always be considered, which makes diagnostic clarification with retrograde urethrography necessary prior to further manipulation (e.g. catheterization) [39, 40].

In the acute situation with unstable patients, CT is the main focus within the trauma care protocols of the emergency department [43]. Conventional cystography is comparable with CT cystography regarding sensitivity and specificity; and plays a role more for stable patients or for monitoring of catheter removal [64, 79]. Cystography, whether conventional or with CT, should be performed with at least 350 ml of diluted contrast medium through an inserted catheter [65].

The diagnostic procedure in urethral injuries is dependent on the hemodynamic situation and on accompanying injuries as well as the pattern of injury of the patient.

Retrograde urethrography is a basic diagnostic study that enables assessment of localization and extent of the injury in stable patients [25]. If contrast medium is not visible in the bladder or the posterior ureter is not visualized, an additional antegrade urethrography (micturition cystourethrography, MCU) can give further information regarding the extent of injuries to the bladder neck, the prostate and the membranous urethra as well as ureteral distraction or stricture over longer the length [25].

Flexible cystoscopy can also be used (anteriorly over the suprapubic access point) if retrograde urethrography of the bladder neck or the posterior ureter cannot be assessed, or an approach through the urethral meatus cannot be observed or is not possible [25, 40, 46, 54].

Computed or magnetic resonance imaging with CT/MRI-Urography and cystography are performed to evaluate associated abdominal injuries, particularly in cases of penetrating injury of the posterior ureter [25, 49].

Finally, in some 20 % of cases, it is not possible to perform the cystogram in the initial emergency department phase of treatment because of associated injuries [42]. This may be unavoidable in individual cases; however, it must be performed as soon as possible so that no injuries are missed [42]. On the other hand, if the diagnosis for ruptured bladder is delayed, there are no severe disadvantages for the patient [42].

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2.9 Spine

As a rule, spine injury is suspected in all patients brought to the hospital with potential multiple trauma. In our own hospital population over the years 2000-2002, 34 % (245 of 720) polytrauma patients had spinal injuries.

Other studies have found a rate of 20 % [23]. Conversely, approximately one third of all spine injuries occur with concomitant injuries [27, 78]. Overall, one can assume approximately 10 000 patients per year with serious spinal injuries in Germany, of whom 1/5 involve the cervical spine and 4/5 involve the thoracic and/or lumbar spine [26]. Of multiply injured patients, approximately 10 % will have C-spine injuries [25]. With 1 to 27 injuries/million children/year, pediatric spine injuries are relatively rare in Western Europe/North America [8].

Spine injury as a component of multiple injuries has important consequences regarding the diagnostic and therapeutic approach. First, typical associated injuries, e.g. thoracic or abdominal injuries, must be excluded. If surgical stabilization is required, a comprehensive pre-operative CT evaluation of the injured region is necessary. Positioning options for intensive care depend on the stability of a diagnosed spinal injury. Thus, if the patient's overall condition allows (hemodynamics, temperature, coagulation, intracranial pressure, etc.), it is desirable to assess spinal injury stability either in the emergency department or in the operating room prior to transfer to the intensive care unit.

Medical History

Key recommendation:

2.56	**Recommendation**	**2011**
GoR B	**The medical history is very important and should be collected.**	

Explanation:

Generally, in multiply injured patients, the history comes from a third party. The mechanism of injury is very important information, and should be passed on from the pre-hospital team to the hospital team. Predisposing factors for spinal injuries include polytrauma itself [3, 32, 40], high-speed motor vehicle accidents [3, 14, 27, 85, 99, 132], motor vehicle accidents of patients not secured by safety belts or airbags [69, 85], pedestrians hit by a vehicle [14], falls from a height [13, 32, 40, 111, 116], the influence of alcohol or drugs [122], and increased age [14, 84, 118]. In unconscious patients, the medical history should also include information regarding movement of the extremities and pain complaints prior to loss of consciousness or intubation. Traumatic brain injury and facial injuries are risk factors for cervical spine injury. According to multivariate analysis by Blackmore et al. [14], patients with skull fractures or continuous unconsciousness have markedly higher probability of cervical spine injuries (odds ratio 8.5), while the risk for those with milder injuries, e.g. face/jaw fractures or short-term unconsciousness is much less (OR 2.6). Similarly, Hills and Deane [62] found the risk of C-spine injury in patients with TBI was approximately 4 times higher than in patients without. With GCS less than 8, the risk is 7 times higher. Other studies on the importance of traumatic brain injury [62, 71], loss of consciousness [38, 65, 67, 115, 132], and facial skull fractures [53, 62, 87, 107] confirm the association with spine injuries. Only one study with large patient numbers reported a tendency for a decreased risk of C-spine injuries in patients with facial or head injuries [147], although GCS was a significant predictor. The validity of clavicle fractures as a predictor is doubtful [147].

In the context of demographic changes with increasingly older people, however, spine injuries must be considered even in patients with low-energy accidents. Nelson [96] reported spine injuries in 43 % of "low-velocity" injuries in patients with an average ISS of 15.

Clinical Examination

Key recommendation:

2.57	Recommendation	2011
GoR B	**In the emergency department, clinical examination of spine injuries has high priority and should be performed.**	

Explanation:

Due to its simple and rapid nature, clinical examination of the spine is a valuable diagnostic tool in the emergency department [40]. It is comprised of inspection and palpation of the spine, identifying contusions and hematomas as well as deformities of the spinous processes or widening between segments. Head or torso pain can suggest spine injury. Tenderness on palpation, distraction, or movement as well as involuntary deformities are further signs of spine injury [20, 111]. As long as the patient is conscious, motor and sensory functions should be tested. Neurological examination should be performed and findings should be precisely documented in a standardized fashion, if possible according to the ASIA-IMSOP (American Spinal Injury Association-International Medical Society of Paraplegia) classification form [25, 26]. For monotrauma, there are good, validated, clinical decision-making rules [10, 63, 133, 134], which enable exclusion of a spine injury and prevent unnecessary radiation. However, these rules are not transferable to polytrauma patients, because here, prehospital measures (especially intubation) and concomitant injuries (particularly head injuries) generally make reliable history and examination impossible [29, 141], since the patient cannot respond or can only respond in limited fashion. Cooper et al. [32] found that pain from a spine fracture was reported in only 63 % of severely injured versus 91 % in less seriously injured patients; patients with TBI were not included in the study. Similar numbers (58 % vs. 93 %) were reported by Meldon and Moettus [89], so that clinical examination was considered reliable only with a GCS of 15. Mirvis et al. and Barba et al. observed that some 10-20 % of all patients who appear to be severely injured are in fact less seriously injured, and thus, can be reliably assessed and spinal injury clinically excluded [11, 92]. From this follows that the clinical examination in polytrauma patients depends largely on overall injury severity. In patients brought to the hospital with suspected polytrauma, then, radiological evaluation of the spine can be potentially foregone only when injury severity is less than expected (ISS $<$ 16). This, however, is outside the focus of this guideline. In cases of polytrauma, clinical diagnosis is not sufficiently reliable to exclude a suspected spine injury. On the other hand, when specific signs of spinal injury are present, the clinical examination can confirm a suspected diagnosis [14, 50, 132]. Despite low sensitivity, due to high positive predictive value ($>$ 66 %), the following signs enable a suspected diagnosis in cases of polytrauma [68]: palpable step formation in the midsagittal plane, tenderness on palpation, peripheral neurological deficits, or hematoma over the spinal column. The work of Holmes et al. [67], Gonzalez et al. [50], and Ross et al. supports the value of clinical findings. For the clinical examination, Gonzalez et al. and Holmes et al. report a sensitivity over 90 % for the C-spine and up to 100 % for the thoracic/lumbar spine, although patients with historical risk factors (painful or consciousness-impairing concomitant injuries) are set apart as a clinical risk group. Thus, these studies are not transferable to polytrauma. In unconscious trauma patients, slack muscle tone, particularly of the anal sphincter, lack of pain response, purely abdominal breathing, and priapism suggest spinal cord injury. Thus, the value of clinical examination is overall somewhat better than the history, even though some of the studies were conducted with monotrauma or mixed patient populations. The bottom line is that the presence of clinical symptoms can predict spine injury. Their absence, however, does not reliably rule it out.

Diagnostic Imaging

Key recommendation:

2.58	Recommendation	2011
GoR B	**Spine injuries should be evaluated with imaging after hemodynamic stabilization and before transfer to the intensive care unit.**	

Explanation:

In principle, diagnostic assessment of the spine should be completed as soon as possible, because continuing immobilization makes medical and nursing measures (e.g. positioning, central venous access, intubation) more difficult, and the immobilization itself may have unwanted effects (e.g. pressure ulcers, infection) [94, 144]. The diagnostic assessment of hemodynamically unstable patients presents a challenge. Prioritization is used, so that life-threating injuries (e.g. epidural hematoma, pneumothorax) are treated and also operated first. Once this goal is attained, if there are no other contraindications (e.g. hypothermia), the spine can be assessed with imaging as described above prior to transfer to the intensive care unit. If this is not advisable because of the situation, for example, because there would be no immediate consequences, the spine will be radiologically cleared once the overall condition has been stabilized, generally on the following day [142]. In individual cases, other injuries make it necessary to forego primary imaging of the spine [142]. In this case, the usual precautions must be applied until further notice: C-spine support, positioning and turning en bloc, re-positioning with roll-board, vacuum mattress, etc. [47, 120]. "Radiologic exclusion" means that there is no observed displacement or unstable spine fracture on spine x-rays or CT. Consistent spine immobilization can be released only after diagnostic imaging has been performed or when the patient has recovered enough for an adequate clinical exam to exclude spine fracture. Individual authors deliberately forego primary diagnostic imaging in cases of minor injuries when it seems likely that the patient will be able to be evaluated clinically within 24 hours, to circumvent unnecessary studies [20]. However, this is seldom the case with multiple injuries, so this approach is not recommended here.

Key recommendation:

2.59	Recommendation	2011
GoR B	**Depending on the hospital facilities, the following spine imaging should be performed on the hemodynamically stable patient in the emergency department: preferably multi-slice spiral CT from head to pelvis, or alternatively, conventional radiographs of the entire spine (AP and lateral, odontoid views).**	

Explanation:

Often in clinical practice, plain x-rays are used for diagnosis followed by focused CT for further workup [41, 93]. In contrast to the remainder of the spine, radiological evaluation of the C-spine has highest priority. Assessment can be done with CT and conventional radiographs (AP, lateral, and odontoid views). The lateral C-spine view alone is not sufficient to rule out bony injuries [30, 126, 135, 145, 149]. The following requirements must be fulfilled: in the lateral view, all cervical vertebrae should be visualized [46, 95]. On the AP projection, the C2-T1 spinous processes should be visualized, and on the odontoid view, the lateral masses of C1 and C2 must be easily evaluated [39]. The 45° oblique views for C7/T1 alignment, swimmer's, and similar projections have decreased priority as they provide less informative value, waste time, and give high radiation dose [43, 86, 110]. When necessary, oblique views should take priority over swimmer's views [72]. Other authors have found that patients with inadequate visualization of the C7-T1 junction on primary imaging were better evaluated with oblique views than CT [75], because CT could be avoided in more than 10 % of cases. In unconscious patients, when there is reason to suspect ligamentous injury, functional views of the C-spine should be taken by the physician with an image intensifier to exclude them [2, 37, 82, 125]. In conscious patients, sensitivity is 92 % and specificity 99 % [20]. However, as pathology is rarely detected on functional views, the routine and even targeted use of them is of questionable value during primary diagnostic imaging [5, 52, 82, 105]. Overall, negative findings on functional images cannot yet be considered as evidence to exclude instability. Computed tomography or especially magnetic resonance imaging, however, provide alternatives (see below). Overlooked musculoskeletal injuries occur in approximately 12 % of polytrauma cases [51]. The cervical spine is the most common [4, 24, 117, 138]. The reasons for this are radiographic studies that are inadequately or not at all performed, or inconsistent follow up on necessary diagnostic assessments [46, 88, 90, 117], which is why unconscious patients without imaging of C0-C3 and/or C6/C7 should be evaluated with CT [20, 139]. 20 % of spine injuries are overlooked because diagnostic assessment is not complete [16, 34]. This has been confirmed with data from 39 polytrauma patients, of whom nine had C-spine injuries, only six of whom could be diagnosed with conventional x-ray. In the remaining three patients, however, additional studies (1x functional views and 2x CT) were required [124]. The "polytrauma" diagnosis itself involves a considerable risk that important injuries will be overlooked on the primary survey [113]. Fifty percent of missed injuries in polytrauma are spine injuries. One result of this is prolonged hospitalization time and need for additional surgeries [117]. Thus, in polytrauma it is recommended to routinely image the entire spine [36, 100]. Particularly in cases of blunt, high energy traumas and falls from a great height, injuries with secondary fractures at other levels are seen with a frequency of 10 %. Thus, thoracic and lumbar spine must also undergo x-ray in two planes [26, 148].

Computed Tomography

Key recommendation:

2.60	Recommendation	2011
GoR B	Regions with pathological, suspicious, and non-assessable findings on conventional radiographs should be further evaluated with CT.	

Explanation:

Due to its greater diagnostic accuracy for detecting spinal injuries, preference should be given to diagnostic CT imaging, if available [6]. Another practical advantage of CT diagnosis is the markedly more rapid clearing of the spine compared to conventional radiography [57, 60, 61], because inadequate images, for example of the cervico-thoracic junction, almost never occur. Generally, diagnostic CT is performed with intravenous contrast medium. CT is also considered beneficial in children, even though the radiation dose, with approximately 400 mRem (Millirem), is higher than that of conventional radiographs (150-300 mRem), according to a pseudorandomized study [1]. Despite the problem mentioned above, it is recommended that children maximize their chances for clinical findings [54]. Basically, the emergency department approach to trauma in children does not differ from that in adults. Detected spine injuries should not undergo surgery without CT [64], as assessment and classification of the fracture often change significantly after CT compared to the initial plain x-ray [57, 59]. Preoperative CT imaging and analysis is particularly important in fractures with rotational instability [127]. The spiral CT from head to pelvis, without conventional radiographs, is particularly suitable for evaluation of the spine in polytrauma because it saves time, is more reliable than conventional radiographs, requires fewer positioning maneuvers, and is less expensive [97]. If the spine is normal on CT, additional conventional radiographs are superfluous [21, 22, 28, 108, 119], because the negative predictive value is almost 100 %. With the current state of universal availability, diagnostic CT imaging seems to be the tool of choice for the detection of spine injuries in polytrauma patients during the emergency department phase of care [73].

Cervical Spine (C-spine)

In 2000, Harris et al. [55] reported conventional radiography as unsatisfactory for the evaluation of C-spine injuries, so that in polytrauma cases CT, or if necessary, magnetic resonance imaging, was recommended. CT is significantly more accurate than conventional radiography for C-spine injuries. In a study of 70 patients, conventional radiography identified 38 with C-spine injuries, while CT identified 67 [123]. A current meta-analysis [66] and the review studies by Crim et al. 2001 [33] and Link et al. 1994 [83] found similar results. Conventional lateral x-ray views detected 60-80 % of C-spine injuries, and CT 97-100 % [103] (Table 2). Additional studies have found that CT layer thickness affects diagnostic accuracy [59], which must be taken into account when evaluating older studies using CT equipment that would be obsolete by today's standards. Based on figures in the literature, Blackmore et al. also concluded that primary diagnostic CT offers better clinical and cost-effective results compared to conventional radiography in patients with average to high risk of spine injuries [15]. CT examination of the C-spine offers not only accurate assessment of bony injuries, but also detects disco-ligamentous injuries, which are associated with instability. Vanguri et al. [143] demonstrated this, where disco-ligamentous instability was detected on CT in 38 % of cases. CT of the C-spine has high value for observing indirect signs such as teardrop fractures, widened segment gaps, and pre-vertebral hematomas.

Thoracic/Lumbar Spine (T-spine/L-spine)

Table 3 summarized the important studies on diagnostic CT for T-spine/L-spine injuries of polytrauma patients in the emergency department. Here there is also markedly higher sensitivity of CT compared to conventional radiography. It must be noted that not all incidental findings such as transverse process avulsions were clinically relevant, but they could also suggest other relevant injuries (abdominal injuries). There are also benefits regarding time and operative planning. According to Hauser et al. 2003 [57], the time required to adequately clear the spine with conventional radiography was 3 hours, and 1 hour for CT. The rate of incorrect fracture classification was 1.4 % for CT, and 12.6 % on conventional radiography.

Concomitant Injuries of the Head/Thorax/Abdomen

To assess the spine and associated injuries in polytrauma, an initial standard CT from head to pelvis is recommended, which takes approximately 20 minutes [81]. Computed tomography on the day of admission is indicated particularly in cases of C-spine injury combined with TBI [124]. For thoracic spine fractures, an emergency CT chest is indicated due to the high rate of complicated thoraco-pulmonary injuries [49]. The constellation of L-spine injuries and abdominal trauma manifesting with internal bleeding into the abdominal wall after seat belt injury also encourages the use of CT to enable simultaneous assessment of the abdomen [12]. Miller et al. 2000 [91] and Patten et al. 2000 [101] also refer to the importance of transverse process fractures as important indicators of concomitant abdominal injuries, for which CT is recommended. Moreover, assessment of the thoracolumbar spine with CT is also recommended in cases of acetabular and pelvic fractures [7, 59]. In conventional radiography, significant spine injuries were overlooked in 11 % of cases with transverse process fractures and only detected when CT was performed. For this reason, CT is considered a requirement for assessment of these fractures [79].

Magnetic Resonance Imaging (MRI)

Overall, magnetic resonance imaging plays a quantitatively subordinate role for polytrauma during the emergency department phase of care [131]. For logistical reasons (access, metal debris, time required, availability), MRI is generally not expedient in the acute phase of polytrauma management. The main indication for MRI is in the evaluation of unclear neurological deficits. In particular, lesions of the spinal cord, the intervertebral discs, and the ligaments can be visualized [33, 48, 76]. However, Patton et al. [102] consider the search for ligamentous injuries with MRI superfluous, considering the rarity of this injury. No studies have directly compared conventional functional views and MRI images; thus, both options seem to be worth recommending. With sensitivity of only 12 % and specificity of 97 %, MRI is not suitable for the detection of fractures [77]. MRI is indicated over the course of follow up for neurological symptoms and has partially replaced functional views for defined situations, for example in Hangman fractures [74]. In general, there is no need to worry about false negative results, but specificity is low [20]. If a neurological deficit is present without correlating morphology on CT, MRI of the corresponding section of the spine is urgent. Additional indications arise occasionally in early post-operative or post-traumatic follow up to evaluate for, for example, intraspinal epidural hematomas, pre-vertebral bleeding, or intervertebral disc injuries [35, 130, 146].

A retrospective analysis by Pourthaheri et al. [106] of 830 cases found a high value for MRI regarding pre-operative planning for C-spine injuries. Here, information obtained through the pre-operative MRI imaging impacted the choice of operative approach to a significant degree. In 81 % of cases this was related to a residual spinal cord compression, and in 9 % to occult instability. However, the use of diagnostic MRI is feasible only in hemodynamically stable patients, since it still is a time-consuming and personnel-heavy procedure.

Emergency Procedures such as Reduction and Cortisone Administration

Key recommendations:

2.61	**Recommendation**	**2011**
GoR B	**In the exceptional case of emergency closed reduction of the spine, this should only be performed after adequate CT imaging of the injury.**	
2.62	**Recommendation**	**2011**
GoR 0	**Administration of methylprednisolone (NASCIS protocol) is no longer standard, but it can be initiated within 8 hours of the injury in cases of neurological deficit and confirmed injury.**	

Explanation:

Precise analysis of the spine injury must be undertaken prior to each reduction, i.e., with careful analysis of the imaging (CT). Despite a poor level of evidence, the recommendation has been upgraded due to the risks of complications. Reduction is generally performed immediately prior to surgery in the operating room or open during the procedure, followed by operative stabilization of the reduced injury. Caution is required during closed reduction without operative stabilization and/or disc removal, as the disc can herniate posteriorly, with detrimental neurological effects [51]. On the basis of three randomized studies [18, 98, 104], a Cochrane review [17] found that methylprednisolone improves neurological outcomes a year after trauma compared to placebo, when it is given within 8 hours of trauma. The recommended dose (NASCIS protocol) is methylprednisolone 30 mg/kg body weight i.v. over 15 minutes within the first 8 hours after trauma, then 5.4 mg/kg BW per hour for 23 hours. The NASCIS-3 study found that administration of methylprednisolone over 48 hours showed a tendency for improved results [19] and was recommended there for patients in whom therapy was begun 3 hours or more after trauma. In cases of verified neurological symptoms with corresponding CT confirmation of spinal cord narrowing, the NASCIS (National Acute Spinal Cord Injury Study) protocol can be begun at an early stage [9]. This can shorten rehabilitation time. However, other analyses have found no effects with cortisone treatment [128, 129] or do not recommend cortisone treatment because no positive effects were evident [70]. In addition, the validity of the NASCIS-2 study results has been questioned [31]. The newest results on corticosteroid administration in TBI [112] have also cast a shadow on the effectiveness of steroids in spinal cord injury. Although high-dose steroid administration to surgical/trauma patients is considered safe overall and to some extent even advantageous [114, 121, 137], the possible side effects are an important argument against steroid administration according to the NASCIS protocol [80, 136]. Known complications of steroid administration in patients with spinal cord injuries include infections [44, 45], pancreatitis [58], myopathy [109], psychological problems [140], and severe lactic acidosis when high dose methylprednisolone is combined with i.v. epinephrine [56].

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2.10 Extremities

Importance of Evaluation and Examination

Although there are no scientific investigations verifying the importance and required scope of physical examination in the emergency department trauma care area, this examination remains an indispensable procedure to recognize clinical signs and make (suspected) diagnoses. The systematic examination of the extremities of the undressed patient "from head to toes" serves as the first line detection of relevant, sometimes dire injuries that may require diagnostic radiological studies, immediate and specific therapy, and practical decisions to be made while still in the ED [1,2]. It is used to estimate overall injury severity. The examination of the extremities includes close inspection and manual examination of the extremities for any type of external signs of injury such as swelling, hematoma, or wounds. Closed and/or open soft tissue injuries are then classified. Clear signs of fracture are recorded. Systematic examination of the extremities enables clinical detection or narrowing down of fractures, dislocations, and/or fracture-dislocations. The large and small joints should be examined for stability.

Another goal of the primary examination is the rough delineation of neurovascular injuries. Potential compartment syndromes should be excluded. Complete neurological exam of all extremities can be performed only in conscious patients; otherwise, at least reflex status should be checked. The distinction between central and peripheral neurological etiology is essential to manage extremity injuries.

Missed extremity injuries are found retrospectively, particularly in unconscious and multiply injured patients. Often, these injuries require operative management [3]. The incidence of missed injuries is independent of emergency department assessments interrupted for emergency surgery.

Examination of the extremities is sometimes neglected when the patient is unstable, and injuries are overlooked [4, 5]. Another source of error is the examiner-dependent evaluation of radiographs, which can result in misinterpretations [6-8].

In this case, process optimization and controlled training [9] as well as the introduction of guidelines lead to improved patient care [10]. Overlooked extremity injuries are rarely life-threatening, and can often be diagnosed and surgically managed secondarily once the multiply injured patient has been stabilized [11].

Diagnostic Equipment

Key recommendations:

2.63	**Recommendation**	**2011**
GoR B	**If the overall condition of the patient allows, in cases of direct or indirect evidence of fractures, extremities should be examined with the appropriate radiological study (radiographs in two planes or CT).**	
2.64	**Recommendation**	**2011**
GoR B	**Radiological studies should be done as soon as possible.**	

Explanation:
The duration of emergency department care affects the results of treatment and the morbidity/mortality of severely injured patients [10]. There is no absolute value to follow such as, e.g. the "golden hour" [12].

In certain areas, the scope of diagnostic radiography can be limited by performing a thorough clinical examination. For example, in knee injuries (as monotrauma), a fracture can be ruled out when there is no pain on weight-bearing, no swelling, and no hematoma [13].

To screen particularly for a knee fracture, a lateral x-ray is sufficient. It is 100 % sensitive [14].

If there is clinical suspicion for a bony extremity injury in a stable patient, radiographs should be performed in at least two planes. Deliberately omitting radiographic assessment is only justifiable if emergency room management is interrupted for emergency surgery [2].

There are no known studies of time in the ED and extremity injury outcomes in particular. There are also no studies examining whether deliberate postponement of diagnostic radiography for extremity injuries to shorten time in the ED influences treatment outcomes.

There are several studies showing poor outcomes after delayed treatment of extremity injuries. However, they are not considered in light of delays in the emergency department assessment.

Assessment/Treatment

Reduction of Obvious Deformity

Key recommendations:

2.65	**Recommendation**	**2011**
GoR B	**Deformity and dislocations of the extremities should be reduced and immobilized.**	
2.66	**Recommendation**	**2011**
GoR B	**The reduction results should not be altered by other interventions.**	

Explanation:
An injured extremity that has been correctly immobilized by emergency rescue services should be left alone in the ED until definitive care. Any changes in immobilization at the area of injury can lead to worsening soft tissue damage and pain, especially in unstable bony injuries [15]. A secure transfer from the emergency rescue services avoids unnecessary re-positioning. There have been no scientific studies to date exploring whether re-positioning maneuvers in the emergency department affect extremity injuries.

With pre-hospital care of injured patients performed by the emergency rescue service, it can be assumed that extremity injuries have been immobilized in the neutral position. If this has been performed correctly, transfers and re-positioning maneuvers of the entire patient have almost no effect on the individual extremity injuries. If immobilization is performed correctly, it is unnecessary from a medical perspective to remove or alter it until the patient is in the pre-operative area.

In the literature, there have been no reported cases of lack of pulse after a pre-hospital fracture reduction.

Open Fractures

Key recommendation:

2.67	**Recommendation**	**2011**
GoR B	**If sufficient reliable information has been provided by the emergency rescue services, a sterile emergency dressing should be left in place until reaching the operating room.**	

Explanation:
In the ED, open fractures are to be treated according to the basic principles of aseptic wound care. In principle, open fractures are a surgical emergency requiring immediate

operative management. The most important factors regarding potential infections are outside of the emergency department, and thus: dressings should not be opened repeatedly, because of the infection risk. Resistant hospital pathogens are more dangerous than germs collected at the accident scene. Merritt found a direct association between frequency of infection and exposure [16, 17].

Pulseless Extremity

Key recommendations:

2.68	**Recommendation**	**2011**
GoR B	**If an extremity lacks a peripheral pulse (Doppler/palpation), further diagnostic studies should be performed.**	
2.69	**Recommendation**	**2011**
GoR B	**Depending on the findings and patient condition, conventional arterial digital subtraction angiography (DSA), duplex sonography, or angio-CT (CTA) should be performed.**	
2.70	**Recommendation**	**2011**
GoR B	**In the case of undiagnosed vascular injuries of the extremities, intraoperative angiography is preferable to diagnostic studies in the emergency department, to reduce ischemia time.**	

Explanation:
Compared to the sensitivity of other diagnostic equipment, duplex ultrasound is at least equivalent to invasive arteriography [18]. Good results from ultrasound are largely dependent on the examiner [19, 20].

Ischemia time is crucial for the prognosis of the extremity as well as the patient overall. Rapid diagnosis with injury localization is essential to enable rapid surgical management.

Vascular lesions cannot generally be diagnosed solely on clinical findings. Injuries of the large vessels require rapid and definite assessment in the ED. Depending on the examiner, duplex ultrasound fulfills these requirements best. If there is already a clear indication for surgery, intraoperative angiography is preferable to diagnostic procedures in the ED. Here, as in the ultrasound studies discussed above, hospital layout plays an important role, so that a general recommendation must be limited.

More recent studies have found that in stable patients, CT angiography is preferable to conventional arterial digital subtraction angiography (DSA). The procedure for computed tomography angiography (CTA) is much less time-consuming and also more cost-effective [21]. It is less invasive than DSA and the rapid development of technology today enables visualization of all arteries in shorter time. However, its value is limited due to the large quantity of iodine-containing contrast medium as well as high radiation exposure. Calcified plaques also compromise precise visualization, particularly for medium and small arteries [22, 23]. The extent of ischemia in the peripheral extremities depends on localization and the length of vascular obstruction as well as the presence of existing collateral circulation. In a healthy vascular system, even short obstructions and/or isolated interruption of an artery to the extremity can lead to necrosis of the dependent musculature and loss of limb.

In general, “the healthier the vascular system, the shorter the tolerance for ischemia.”

In polytrauma, there is the added challenge that extremity injury triggers arterial vascular spams, which themselves result in a marked decrease in circulation to the extremities [24].

With prolonged ischemia time (after approximately 3-6 hours), the risk of compartment syndrome after successful revascularization must be considered. Pronounced direct soft tissue damage can further worsen the prognosis for revascularization.

Compartment Syndrome

Key recommendation:

2.71	**Recommendation**	**2011**
GoR 0	**In cases of suspected compartment syndrome, invasive compartment pressure measurements can be performed in the emergency department.**	

Explanation:
Compartment syndrome is time-dependent and can develop dynamically. It is produced by a rise in the intrafascial pressure of the muscle compartments. It can affect all areas of the extremities, primarily the lower leg. Aside from fractures, other etiologies include burns and positioning injury. During the clinical examination, there are many compartment signs, which are not always relevant: pain, increased by passive tension of the affected muscle compartment, swelling of the affected muscle compartment, sensory disturbances of the muscle dermatome.

When the diagnosis is suspected based on these clinical signs, objective measurement of the intrafascial pressure is promptly carried out, if necessary with a starting value in the ED. Continuous pressure monitoring is useful. The compartment pressure measurement in mmHG is subtracted from the diastolic blood pressure in mmHg; a value less than 30 mmHg is considered pathological [25, 26].

Particularly in polytrauma, with massive infusion and transfusions, the onset of compartment syndrome must be considered. Clinical evaluations for threatened or manifest compartment syndromes are often insufficient in sedated patients, so that only bloody measurements of intrafascial pressure offer data to assist clinical decision-making. It must be noted here that the accuracy of compartment pressure measurements is examiner-dependent and false positives and negatives can occur.

Amputation Injuries

In multiply injured patients, the expedience of limb preservation attempts needs to be discussed when soft tissue injuries have reached grade 3 for closed and grade 4 for open fractures. It is particularly important in polytrauma patients to consider that a protracted attempt at preservation with long operative time can jeopardize vital functions.

The decision to attempt limb salvage is advisable only after the primary survey has been completed according to ATLS® and ETC. Only then can an assessment including the overall injury picture be made regarding patient stability for an extensive time-consuming surgical intervention.

On the other hand, experience tells us that the indication to attempt salvage should only be made by a competent surgeon after detailed inspection of the injured soft tissue. This can only take place in the operating room.

Thus, the question remains whether emergency subtotal amputation should be performed in the ED for an unstable patient. This is a case-by-case decision, which depends more on the pattern of other injuries than on the findings of the extremity itself. The literature offers many case studies of successful reconstructions or replantations of extremities. It is not possible to derive a recommendation. Carrying out an investigation seems unrealistic.

For open extremity injuries in polytrauma patients, a decision must be made in the ED regarding the patient's capacity to undergo surgery including the extensive operative time expected for a limb salvage procedure.

Emergency amputation in the ED remains an option for unstable patients and the decision to carry it out is made by the trauma leader according to individual factors. There is the rule: "Life before limb."

Diagnostic CT

During emergency department trauma assessment, CT is generally used as a first line tool for injuries of the torso, including the pelvis. Because of structural measures as well as software development, diagnostic CT is increasingly used over conventional radiography for extremities during emergency trauma management.

Whether conventional diagnostic radiography can be forgone altogether is currently decided on a case by case basis. A general recommendation cannot be made. In a retrospective study of comparable patient groups, Wurmb et al. found an average assessment time of 23 minutes for 82 patients receiving complete injury assessments with CT, and 70 minutes for 79 patients first undergoing conventional radiographs followed by targeted CT [27]. However, Ruchholtz et al. highlight injuries overlooked on CT as well as the increased radiation exposure [28].

For stable patients in the ED with suspected talus or scaphoid fractures, diagnostic CT can be added to the conventional diagnostic radiography for operative planning and to avoid missing fractures in these regions [29, 30].

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2.11 Hand

For diagnosis and surgical management of hand injuries, especially in polytrauma, there are no studies with level of evidence greater than 4. The available literature describes only injury frequency and combinations. Recommendations regarding assessment and care come only from expert opinions. Thus, the following evidence-based recommendations are derived more from studies investigating hand injuries as a result of monotrauma.

Hand injuries, especially fractures, can occur in up to 25 % of patients with multiple injuries [1, 12, 15, 18]. The most common injuries are hand fractures including the distal radius, which occur in 2-16 % of all polytrauma patients [1, 4, 10, 13, 19]. Tendon and nerve injuries are less common with 2-11 % and 1.5 %, respectively [15]. Amputations at the hand occur only in 0.2-3 % of polytrauma cases [3, 11]. Severe combination hand injuries are also less common in polytrauma patients [17].

Primary Assessment

Key recommendation:

2.72	Recommendation	2011
GoR B	**Clinical evaluation of the hands should be performed within the basic survey, because it is crucial to determine the need for further examinations with special equipment.**	

Explanation:
The probability of hand injury does not depend on the severity of the polytrauma. It can also not be assumed that the chance of missing a hand injury increases with increasing injury severity [15]. However, hand injuries that are initially missed and not treated can lead to considerable functional impairment [8]. During the emergency assessment, closed tendon injuries (tractus intermedius, distal extensor tendons, avulsion of the deep flexor tendons), carpal fractures, and dislocations are frequently missed [6, 9, 16]. The basic clinical assessment should include inspection for skin damage, swelling, hematoma, deformity, limited mobility, as well as perfusion (radial and ulnar arteries, capillary refill of the fingertips) [17].

Key recommendation:

2.73	Recommendation	2011
GoR B	**In case of suspected hand injury, basic radiological work-up should include radiographs of the hand and the wrist, each in two standard planes.**	

Explanation:
Unconscious patients with clinical evidence of hand injury (see above) should have radiographs of the hand and the wrist taken in two planes. Special attention should be paid to potential carpal fractures and dislocations. When there are clinical signs of phalangeal fractures that can't be excluded or well characterized on hand radiographs, especially in cases of serial fractures of multiple fingers, it is advised to obtain films of the individual finger(s) in two planes as soon as possible [16, 17].

Key recommendation:

2.74	Recommendation	2011
GoR B	**Doppler or duplex ultrasonography should be performed when there is clinical suspicion of an arterial injury.**	

Explanation:

When arterial injury is suspected, Doppler or duplex ultrasound can yield a rapid, accurate diagnosis [5, 7, 14]. Angiography is then indicated for the remainder of unclear cases with urgent clinical suspicion of arterial injury, if the overall condition of the patient prohibits operative exploration [7] or when the location of the lesion is undefined [2]. The Allen test permits reliable confirmation of patency of the radioulnar anastomosis and both forearm arteries [5].

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2.12 Foot

Assessment of Foot Injuries

In unconscious patients with multiple injuries, foot injuries can be excluded by repeated clinical examinations. In polytrauma patients, foot injuries are initially missed with an above average frequency. The reasons for this are the more eye-catching and life-threatening injuries, deficient radiographic technique in the emergency situation, variable clinic standards, lack of experience by the examiner, sometimes in terms of case numbers of various foot injuries, as well as communication deficits in the treatment of polytrauma patients by several teams [2, 5-8, 11, 13, 14, 19]. Thus, in order to avoid missing foot injuries with potentially serious long-term consequences in unconscious patients, clinical examinations need to be repeated when there are even subtle signs of injury [7, 20]. In a retrospective analysis, Metak et al. [11] reported that 50 % of all overlooked injuries in the lower extremity are in the foot, and recommended a thorough clinical examination every 24 hours. When there is clinical suspicion of foot injury, first, standard radiographic views (see below) are indicated, followed by stress views and/or foot CT if these don’t provide sufficient information.

Table 13: Standard Projections of the Foot (Review in [19, 20]):

Pilon, ankle joint	Ankle joint ⊥
Talus	Ankle joint ⊥, Foot dorsoplantar (beam tilted 30° superior-inferior)
Calcaneus	Calcaneus lateral, axial, Foot dorsoplantar (beam tilted 30° superior-inferior)
Chopart/ Lisfranc	Foot true lateral, Foot dorsoplantar (for Chopart, tube tilted 30°, for Lisfranc 20° superior-inferior), Midfoot 45° oblique view
Midfoot/ Toes	Mid/Forefoot AP, 45° oblique views, true lateral

The appearance of tension blisters on the foot must be considered an indicator of ischemic skin damage or compartment syndrome [12]. In addition to clinical criteria, Doppler ultrasound is recommended for initial assessment of foot vascular status [3, 15]. Routine angiography for an absent Doppler signal remains controversial [16], but is indicated if the goal is complex reconstruction [9]. An important indicator of skin perfusion is the ankle brachial index. If the Doppler flow is at least 50 % of that of the brachial artery, the rate of wound healing is 90 % [17]. The same has been confirmed for a transcutaneous measurement of oxygen tension over 30 mmHg [18]. Worse healing rates after operative interventions can be expected in the elderly (peripheral arterial occlusive disease, pAOD), in diabetics, and in smokers [1, 4, 10].

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2.13 Mandible and Midface

The incidence of injuries to the mandible and midface in multiply injured patients is approximately 18 % [2, 19]. The most common concomitant injuries in craniofacial fractures are cerebral hematoma, with over 40 %, followed by lung contusion with over 30 % [1].

Examination

Key recommendation:

2.75	Recommendation	2011
GoR B	**Functional and aesthetic injuries of the head and neck region should be ruled out during the clinical examination of polytrauma patients.**	

Explanation:

Consultation of qualified specialists (maxillofacial/ENT surgeons according to availability or in-house arrangements) is advisable for all patients with evidence of mandibular and/or midface injuries, although this depends on the specialty qualifications of the participating physicians and space as well as organizational conditions of the facility [12, 15, 22].

The examination should be carried out with thorough inspection and palpation [3, 7]. Among other things, it should confirm external and internal injuries (e.g., bruise marks, hematoma, abrasions, soft tissue injuries, bleeding, tooth injuries, eye injuries, intracranial fluid leaks, brain extrusion, as well as mandibular and midface fractures).

Diagnostic Assessment

Key recommendation:

2.76	Recommendation	2011
GoR B	**Further diagnostic studies to complete the assessment should be performed when there are clinical indications of mandible and midface injuries.**	

Explanation:

Conventional radiography and/or CT are used to complete the technical assessment [13]. Panoramic views (orthopantomogram), paranasal sinuses views, specific dental x-rays, and Clementschitsch (PA mandible) or lateral skull films are performed. Computed tomography enables visualization of signs of increasing intracranial pressure, asymmetries, fractures, and larger maxillofacial defects as well as the grade of displacement [9, 11, 23, 24]. Axial, sagittal, and coronal slices can be reconstructed [9, 18] (EL 3, EL 4). Preoperative planning can be made more precisely with CT [4, 9]. This enables reduced and operating time and higher quality [9, 21].

For small deformities, lower radiation exposure can be achieved with radiographs in two planes [17]. Pages et al. point out that the effects of ionizing rays are increased by a factor of 3 in children, and particular attention should be paid regarding danger to the eyes [14].

The methods of diagnostic imaging (radiography or CT) are generally determined according to the type and localization of concomitant injuries and local equipment availability.

In cases of orbital involvement, some authors recommend visual evoked potentials (VEP) or electroretinogram (ERG) to evaluate the optic nerve [5, 6, 8]. This can offer objective evidence regarding optic nerve function and enable early intervention especially in cases where functional diagnostic testing is not possible or unreliable (as a result of unconsciousness, sedation, massive swelling).

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2.14 Neck

Key recommendations:

2.77	**Recommendation**	**2011**
GoR A	**Securing the airway must take priority when treating neck injuries.**	
2.78	**Recommendation**	**2011**
GoR B	**In case of tracheal rupture, tears, or open injuries, surgical exploration with tracheostomy placement or direct reconstruction should be performed.**	
2.79	**Recommendation**	**2011**
GoR B	**For all neck injuries, early intubation or, in cases where this is not possible, tracheostomy should be considered.**	

Explanation:

Depending on the pattern of injury, intubation must be considered at an early stage. This can be done with transoral, transnasal, transvulnar approaches or via tracheostomy. Even in a completely ruptured trachea, the distal section can be bridged and endoscopically intubated. If oral or transnasal intubation are not possible, tracheotomy must be considered [2].

Tracheostomy is always an elective operation; in acute emergencies, emergency tracheotomy should be performed over a coniotomy approach [13]. In case of tracheal rupture, tears, or open tracheal injuries, surgical exploration with tracheostomy placement or direct reconstruction should be performed. Conservative therapy can be attempted in short-distance injuries not involving all layers [6]. The same applies for laryngeal trauma [2, 3, 14].

Diagnostic Assessment

Key recommendations:

2.80	**Recommendation**	**2011**
GoR B	**To determine the type and severity of the injury, CT of the neck soft tissues should be carried out in hemodynamically stable patients.**	
2.81	**Recommendation**	**2011**
GoR B	**When there is clinical or CT-based suspicion for neck injury, endoscopic examination of the traumatized area should be performed.**	

Explanation:

See also the “Imaging” chapter, Key Recommendation 2.129 on page 301. Under certain conditions, CT can also be performed in severely injured patients who are hemodynamically unstable (2016). To avoid generating further trauma with diagnostic or therapeutic measures, first, injuries of the cervical spine should be sought or should be minimized as much as possible with immobilization [10, 12, 14]. Although the consequences of tracheal tears or ruptures van be visualized with diagnostic imaging (CT/MRI/conventional radiography), the lesion itself or parts of it are often difficult to see. For example, subcutaneous emphysema indicates tracheal injury, but often the actual lesion is not identified, or a pronounced neck hematoma is present without detectable source of bleeding on conservative imaging. In addition, endoscopic examination is recommended for the diagnostic assessment of cervical injuries [1]. For suspected vascular injuries, duplex ultrasound is a non-invasive alternative that is considered equivalent to angiography [7, 8]; both procedures are considered gold standard for neck vessel injuries. This applies particularly in neck zones I and III according to Roon and Christensen [12]. Supplementary surgical exploration is recommended for zone II injuries. Although this is still debated in the literature, there is no dispute that this approach enables 100 % of defects to be detected and treated if necessary [7, 12].

Therapy

Key recommendations:

2.82	**Recommendation**	**2011**
GoR B	**Open neck trauma with acute bleeding should be initially treated with compression, followed by surgical exploration.**	
2.83	**Recommendation**	**2011**
GoR B	**For closed neck trauma, vascular status should be evaluated.**	

Explanation:

Angiography or duplex ultrasound represent the gold standard for injuries of the neck vessels, especially zones I and III (Roon and Christensen) [12]. Supplementary surgical exploration is recommended for zone II injuries.
The first line choice for functional and trauma evaluation is Doppler ultrasound, because it is the least invasive, quickly performed, and more economical examination method. In terms of diagnostic predictive value, it is at least equivalent to angiography and CT, with less invasiveness, lower costs, and more rapid implementation [7, 8, 12].

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2.15 Resuscitation

Treatment of Trauma-Induced Cardiac Arrest

Key recommendation:

2.84	Recommendation	New 2016
GoR A	**For the treatment of trauma-induced cardiac arrest, it must be underscored that the pathophysiology is different from non-traumatic cardiac arrest, and thus, the procedure is fundamentally different.**	

Explanation:

Traumatic cardiac arrest (TCA) has a very high mortality. For survivors, the neurological outcome is markedly better than for survivors of cardiac arrest from other causes [35, 40, 71]. Zwingmann et al. reported long-term survival rates between 3.3 % and 16.3 %, depending on patient age. Adequate neurological outcomes were attained in 57.4 % of survivors. Leis et al. reported a survival rate of 6.6 % of patients with complete neurological recovery. Maron et al. found a survival rate of 28 % after sudden cardiac death in a subgroup of patients with "commotio cordis." Immediate treatment of potentially reversible pathologies, particularly in TCA, is the foundation of the treatment concept [6, 31, 38, 57, 58, 65]. Several management algorithms and guidelines highlight the need for a stand-alone pre-hospital algorithm including thoracic and pericardial decompression as well as pelvic fracture stabilization and control of external bleeding. In recent years, a series of algorithms have been published taking the specifics of TCA into account. The ERC guidelines for cardiopulmonary resuscitation 2015 discuss the divergent approaches to TCA versus non-traumatic cardiac arrest. In TCA, the response time is critical, and outcome depends on a well-established chain of survival, from advanced pre-hospital management to trauma center care.

Chest compressions are the basic measure for cardiac arrest of all kinds, regardless of etiology. In cases of hypovolemia, tension pneumothorax, or pericardial tamponade, however, chest compressions are not as effective as they are in non-traumatic cardiac arrest. In cases of hypovolemia or obstructive forms of shock like tension pneumothorax or pericardial tamponade, the end diastolic filling volume remains low despite correctly performed external cardiac massage, even in normovolemic patients. Because of this, chest compressions have lower priority in TCA compared to immediate treatment of the above-mentioned reversible causes (e.g., thoracotomy, hemorrhage control) [65]. However, this approach diverges significantly from the universal ALS algorithm for non-traumatic cardiac arrest, in which cardiac etiologies predominate (see also "non-traumatic etiology" section).

Criteria for Cardiac Arrest

Key recommendation:

2.85	Recommendation	Modified 2016
GoR A	**When there are no vital signs, when there is uncertainty regarding a pulse, or when there are other clinical signs suggesting likely cardiac arrest, cardiopulmonary resuscitation procedures must begin immediately.**	

Explanation:

Cardiac arrest after trauma itself is not a hopeless situation [31]. Based on retrospective analyses of patient collectives mostly from the 1980s and 1990s, the ERC Guidelines for Resuscitation 2005 found an average survival rate of approximately 2 %, without serious neurological deficits in only 0.8 %; there was a slightly better survival rate for penetrating over blunt trauma [59]. In the meantime, further evidence has been collected regarding outcomes after treatment for traumatic cardiac arrest, and they are more much more positive. In an evaluation of the DGU Trauma Registry of 10 359 patients from 1993-2004, 17.2 % of polytrauma patients were successfully resuscitated after traumatic cardiac arrest, 9.7 % with moderate to good neurological outcomes (Glasgow Outcome Scale GOS $\geq$ 4, Table 14). 77 (10 %) of the resuscitated patients underwent emergency thoracotomy with a survival rate of 13 % [28]. Other more recent studies have reported survival rates up to 29 % [27, 31, 36, 49, 54, 58, 64, 68]. A few studies have even found comparable survival rates for traumatic and non-traumatic cardiac arrest [15]. Now it must be assumed that traumatic cardiac arrest can be survived more often and with better neurological outcomes than was previously believed.

Table 14: Glasgow Outcome Scale (GOS) [24]:

1. Died, as a result of acute brain hemorrhage
2. Apallic, permanent vegetative state
3. Severely disabled (mentally and/or physically), requiring permanent care, no capacity for employment
4. Moderately disabled, mostly independent but marked neurological and/or psychological impairments, greatly reduced capacity for employment
5. Not/mildly disabled, normal life despite possible mild impairments, slight or without restrictions to employment capacity

The criteria for detecting cardiac arrest in trauma patients is distinct from those detecting cardiac arrest from non-traumatic causes. There are differences in the recognition of impending cardiac arrest [6, 48, 60]. Clinical signs of unsurvivable injury as well as potentially reversible causes of death are unreliable. The "Casper sign," known from legal medicine, describes severe internal injuries without visible external injuries. Before beginning resuscitation measures in TCA, all potentially reversible causes of trauma-induced cardiac arrest must be resolved or excluded [7, 9, 31, 32].

The decision regarding the need to resuscitate the trauma patient must be made according to the most recent Guidelines of the European Resuscitation Council and initiated and/or continued according to indications [65]. In severely/multiply injured patients, the main criterion to diagnose cardiac arrest is also pulseless apnea with or without cardiac electrical activity. In previous resuscitation guidelines, state of consciousness, breathing, and circulation were checked with highest priority [23, 24]. In the meantime, however, studies have found that both evaluation for spontaneous breathing [14, 53] and especially checking for a pulse [14, 17] are fraught with high error rates, even when performed by trained personnel. The low sensitivity in particular could result in a delay to resuscitation.

Medical personnel in the emergency department should spend a maximum of 10 seconds searching for the presence or absence of a central pulse. In case of doubt, or with other clinical signs of probable cardiac arrest (e.g., absence of breathing), resuscitation interventions should be initiated immediately [29].

Unremarkable ECG does not exclude cardiac arrest. Pulseless electrical activity (PEA) must be excluded by pulse measurement for every potentially perfusing ECG rhythm. The presence of an ECG rhythm cannot be used as an indication of circulation [29]. Nevertheless, immediate ECG is an essential component of monitoring and is always included in cardiovascular assessment.

The ECG and observed changes also determine the use and timing of defibrillation when there is suspicion or evidence of cardiac arrest. Shockable rhythms are treated by defibrillation also in cases of traumatic cardiac arrest [29]. Pulse oximetry and especially capnography are essential components of monitoring a polytrauma patient. Both methods are able to detect cardiac arrest (absence of pulse waves on pulse oximetry, quickly dropping $etCO_2$ on capnography). However, there are limitations to pulse oximetry in shock, centralization, and hypothermia. The lack of externally visible evidence of severe injuries (e.g. excessive bruising) does not reliably exclude the presence of severe internal injuries. The "Casper sign" occurs when the patient experiences such a sudden loss of blood that there is insufficient time to create peripheral hematomas prior to cardiac arrest. In addition, because of its high elasticity, the skin over the injury can remain intact despite extensive internal organ lacerations [9]. The consequence is that a patient who appears externally intact can still have suffered a traumatic cardiac arrest.

Non-Traumatic Causes

Key recommendation:

2.86	Recommendation	New 2016
GPP	**In (suspected) cases of non-trauma-induced cardiac arrest in trauma patients, the corresponding European resuscitation guidelines must be applied.**	

Explanation:

Not every patient requiring resuscitation after avoidable trauma suffered cardiac arrest of traumatic etiology. The differential diagnosis should always include non-traumatic causes (e.g. myocardial infarction or arrhythmia) as the provocation of an accident from which a patient is found in cardiac arrest but in whom there are no or only minor injuries. 2.5 % of all out-of-hospital, non-traumatic cases of cardiac arrest occur in motor vehicles. In these cases, there is often a shockable rhythm (ventricular fibrillation, VF/pulseless ventricular tachycardia, pVT) present. In an analysis of 2194 patients in cardiac arrest, Engdahl et al. found that 57 cases (3 %) occurred in a car [18, 31, 62]. Because these cases of non-traumatic cardiac arrest must be treated according to the ALS universal algorithm, it is vitally important that they not be misinterpreted as TCA at the beginning of care [64].

Internal or neurological damage can cause secondary trauma. Frequent causes are:

- Myocardial infarction
- Cardiac arrhythmia
- Hypoglycemia
- Stroke
- Seizure

The medical history, evidence of events immediately prior to the accident, and a systematic evaluation (including 12-lead ECG) after successful resuscitation can help identify the cause for the cardiac arrest.

Special Considerations when Resuscitating Trauma Patients

Key recommendation:

2.87	Recommendation	Modified 2016
GoR A	**During cardiopulmonary resuscitation, the trauma-specific, reversible causes of cardiac arrest (according to the ABCDE protocol; e.g., airway obstruction, esophageal intubation, tension pneumothorax, pericardial tamponade, and hypovolemia) must be diagnosed, excluded, and/or treated.**	

Explanation:

In principle, establishment of the indication for resuscitation must be done according to the ERC Guidelines also in trauma patients [29, 59, 65]. Cardiopulmonary resuscitation is generally only successful when the cause of cardiac arrest can be resolved.

Reversible causes of traumatic cardiac arrest, classified according to the ABCDE trauma protocol, are:

A (Airway):

- Hypoxemia from loss of patent airway as a result of trauma and/or unconsciousness
- Misplaced Endotracheal Tube

B (Breathing):

- Hypoxemia
- Tension pneumothorax

C (Circulation):

- Hypovolemia
- Pericardial effusion/tamponade

Un-decompressed tension pneumothorax is the most common definitively preventable cause of death in traumatic cardiac arrest [28, 31, 32, 57].

Trauma-specific reversible causes of cardiac arrest should be detected and resolved with the following interventions:

Hypoxia

Hypoxemia (e.g., visible cyanosis, low oxygen saturation) from airway obstruction and blunt chest compressive trauma accounts for 13 % of all TCA [31]. Hypoxic cardiac arrest must be resolved with effective airway management and sufficient ventilation. The required interventions include aspiration, visualization with direct laryngoscopy, inspection of the neck for external signs of injury, and tube placement monitoring with auscultation and capnography/capnometry. Studies from Germany have found that esophageal intubation occurs in 7 % of cases. Thus, immediate control of correct tube placement with auscultation and capnometry/capnography right after intubation by the rescue service and on admission to the ED is mandatory [63]. In pronounced hypovolemia, it might be advisable to forego ventilation with increased PEEP, to avoid interference with pre-load and cardiac filling. Especially in hypotensive patients, positive pressure ventilation can worsen hypotension by decreasing venous return. Low respiratory volumes and ventilation frequency help to optimize cardiac preload. Ventilation must be monitored with capnography and the goal should be normocapnia [47, 61].

Tension pneumothorax

Decompression of increased pleural pressure with chest tube placement (bilaterally when necessary) in cases of tension pneumothorax is a positive predictor for survival after post-traumatic cardiac arrest [8, 16, 28, 44].In TCA, bilateral thoracostomy (mini-thoracotomy, surgical opening of the pleura through the mini-thoracotomy) should be performed for decompression in the 4th intercostal space, which can be extended when necessary to a bilateral, transverse thoracotomy ("clamshell" approach). In cases of patients with positive pressure ventilation, simple thoracotomy is more effective than needle decompression and more rapidly performed than chest tube placement [16,19,64].

Hypovolemia

In 48 % of all TCAs, uncontrolled blood loss is the cause of cardiac arrest [31]. With emergency ultrasound (e.g. eFAST) [22,46], and with the collection of hemoglobin, lactate, and bicarbonate (arterial or venous) levels, blood analysis should offer evidence of an abdominal or thoracic source of massive bleeding. The treatment of severe hypovolemic shock consists of several elements. The most important principle is hemostasis without delay, which usually happens through surgical measures, but can also be achieved with radiological interventions if necessary. If hypovolemia is the cause of cardiac arrest, the success rate of cardiopulmonary resuscitation can be increased with hemostasis and volume replacement [1, 26]. Temporary bleeding control should also be performed for TCA with tourniquets, hemostatic dressings, and splinting (e.g., pelvic binders) [61,64]. Over the past ten years, the concept of "damage control resuscitation" (DCR) has become a standard part of the treatment of uncontrolled, massive bleeding. DCR combines permissive hypotension and aggressive coagulation therapy with "damage control surgery," surgical damage control aimed at temporary stabilization of injuries without additional surgical trauma. In cases of unclear evidence, there is general consensus to restrict intravenous fluids until bleeding is surgically controlled. With permissive hypotension, just enough volume is given to maintain a radial pulse [4, 25, 33, 64]. Although the evidence regarding permissive hypotension is minimal, especially in blunt trauma, this concept is used by both military and civilian emergency services, and the goal is systolic blood pressure of 80-90 mmHg. Permissive hypotension is contraindicated in patients with traumatic brain injury, because these patients need high cerebral perfusion pressure due to increased ICP. Because of the risk of irreversible organ damage, permissive hypotension must not be continued for longer than 60 minutes duration.

Pericardial Tamponade and Emergency Thoracotomy

If cardiac arrest occurs after penetrating trauma to the chest or upper abdomen, there is an indication under certain conditions (4-E rule according to ERC 2015, see below) to perform a pre-hospital emergency thoracotomy (clamshell approach) if necessary [21, 65, 69]. According to the guidelines published by Burlew et al., the following criteria should be considered on admission to decide whether emergency thoracotomy should be performed in the ED:

- Blunt trauma with less than ten minutes of pre-hospital CPR,
- Penetrating torso trauma with less than 15 minutes CPR.

The survival rate after emergency thoracotomy is approximately 15 % for all patients and approximately 35 % for patients with penetrating heart injuries. In contrast, survival rates are much lower in patients with blunt trauma, with 0-2 % [6, 64]. In any case, appropriate training is important [11, 51].

Tension pneumothorax

Key recommendation:

2.88	Recommendation	New 2016
GPP	**If tension pneumothorax is suspected in patients with traumatic cardiac arrest, bilateral decompression must be performed with mini-thoracotomy.**	

Explanation:

Tension pneumothorax is the most commonly treatable cause of traumatic cardiac arrest and must be excluded or addressed during CPR. 13 % of severely injured patients with tension pneumothorax develop TCA over the course of management [3, 10, 31, 32, 34]. Findings include symptoms of hemodynamic instability (hypotension, circulatory arrest) and signs of pneumothorax (preceding respiratory distress, hypoxia, unilateral absence of breath sounds on auscultation, subcutaneous emphysema) or mediastinal displacement (tracheal deviation and jugular vein engorgement). During CPR, these signs are not always classic [52]. In intubated patients, endotracheal tube positioning should be verified during the examination if necessary, to avoid misinterpretation if the tube has been advanced too far unilaterally.

Effective treatment of tension pneumothorax in TCA includes endotracheal intubation, positive pressure ventilation, and some form of decompression. The incision and rapid opening of the pleural space under positive pressure ventilation correspond to the initial steps of chest tube placement, which must be inserted only after primary resuscitation, since it requires more equipment and time. In addition, chest tubes can be obstructed (blood clots, lung tissue) or can kink [16, 41].

Key recommendation:

2.89	Recommendation	New 2016
GPP	**For diagnosis of trauma-specific, reversible causes of cardiac arrest, eFAST can be used in the pre-hospital setting and must be used in the emergency department.**	

Although no studies have shown better treatment results from the use of ultrasound during TCA, it is indisputable that ultrasound can exclude reversible causes of cardiac arrest. The following pathologies can be detected with the standardized protocol:

- Pneumothorax
- Hypovolemia
- Pericardial tamponade
- Pulmonary emboli

Pseudo PEA (organized myocardial activity without palpable pulse) can be determined.

Chest compressions

Key recommendation:

2.90	Recommendation	New 2016
GPP	**Chest compressions must not delay measures to correct reversible causes of blunt traumatic cardiac arrest.**	

Explanation:

Chest compressions are the basic measure for cardiac arrest of all kinds, regardless of etiology. In cases of hypovolemia, tension pneumothorax, or pericardial tamponade, however, chest compressions are not as effective as they are in normovolemic situations [13, 36, 39, 64, 68].

Also, depending on the size of the treatment team, chest compressions have lower priority than immediate treatment of reversible causes (e.g., thoracotomy, hemorrhage control). If there are sufficient personnel available, chest compressions must be continued in parallel to treatment of reversible causes.

Key recommendation:

2.91	Recommendation	Modified 2016
GoR B	An intra-arterial catheter should be placed in the emergency department for invasive continuous blood pressure measurement.	

According to expert opinions of the guideline project group, early placement of a catheter into the femoral artery for invasive continuous blood pressure monitoring can objectify the diagnosis of cardiac arrest and the efficiency of resuscitative efforts in the ED. Thus, placement of the intra-arterial catheter should lead neither to interruption nor to delay of cardiopulmonary resuscitation.

Cessation of Resuscitation Measures

Key recommendations:

2.92	Recommendation	New 2016
GPP	Before cessation of resuscitation measures, all potentially reversible causes of trauma-induced cardiac arrest must be excluded or treated.	
2.93	Recommendation	Modified 2016
GoR A	When resuscitation has failed after eliminating all possible trauma-specific, reversible causes of cardiac arrest, cardiopulmonary resuscitation must be ended.	
2.94	Recommendation	2016
GoR A	If there are clear signs of death, or injuries incompatible with life, cardiopulmonary resuscitation must not be started.	

Explanation:

The success of cardiopulmonary resuscitation in TCA depends on the elapsed time of cardiac arrest as well as the ability to eliminate trauma-specific causes of cardiac arrest during resuscitation. Cardiopulmonary resuscitation can still fail despite the thorough implementation of all therapeutic measures (e.g. mini-thoracotomy) to resolve trauma-specific causes of cardiac arrest. If no reversible causes can be detected during CPR, or if treatment measures do not lead to return of spontaneous circulation (ROSC), then resuscitation must be called off.

Recognized signs of death indicate irreversible cellular death in vital organs and are thus signs that CPR should be foregone. If there are clear signs of death, or injuries incompatible with life, cardiopulmonary resuscitation must not be started. The decision to continue or to cease CPR is the responsibility of the treating physicians and must be reached by consensus. A specific amount to time to determine failed resuscitation cannot be given. The American College of Surgeons and the National Association of EMS Physicians recommend the abandonment of resuscitation measures in situations with detectable or inevitable mortality and in apneic trauma patients without a pulse and without organized cardiac rhythm [35, 43]. In the pre-hospital setting, when clear signs of death or injuries incompatible of life are not present, clinical estimates alone are unreliable and when there is doubt, transport to the closest suitable hospital should be attempted [7, 20, 32].

Importance of Emergency Thoracotomy in the Emergency Department for Post-Traumatic Cardiac Arrest

Key recommendation:

2.95	Recommendation	2016
GoR B	Emergency thoracotomy should be performed in cases of penetrating injures, particularly when cardiac arrest has recently occurred and vital signs were initially present.	

Explanation:

Emergency thoracotomy during cardiopulmonary resuscitation can improve prognosis especially in cases of penetrating trauma, and appears advisable particularly if vital signs were initially present [30, 50, 70]. Corresponding availability of logistical and personnel resources is obligatory [56]. Conversely, emergency thoracotomy should be performed with caution in patients with blunt trauma. Emergency thoracotomy is a relatively simple procedure [37, 57, 67, 69]. Lockey and Sherren describe its use within the TCA algorithm also in the pre-hospital setting. Burlew et al. observed an overall survival rate of approximately 15 % after emergency thoracotomy. In contrast to patients with penetrating heart injuries, of whom some 35 % survived, a survival rate of only 0-2 % was found after emergency thoracotomy for patients suffering blunt trauma injuries [6, 42].

The conditions for successful emergency thoracotomy (RT) can be summarized with the 4-E rule according to the ERC Guideline [64, 65]:

- **Expertise (Experience)**
  Teams performing RT must be led by a very well

trained and competent medical specialist and work under structured conditions.

- **Equipment**
  Adequate equipment for the RT procedure and treatment of conditions identified during the procedure must be immediately available.
- **Environment**
  Ideally, RT must be performed in an operating room. It must not be performed where patient access is limited or when the target hospital cannot be easily reached.
- **Elapsed Time**
  The delay from occurrence of cardiac arrest to beginning of RT must not be more than ten minutes.

If one of these four criteria are not fulfilled, RT is useless and only endangers the team [55].

Extracorporeal Circulation

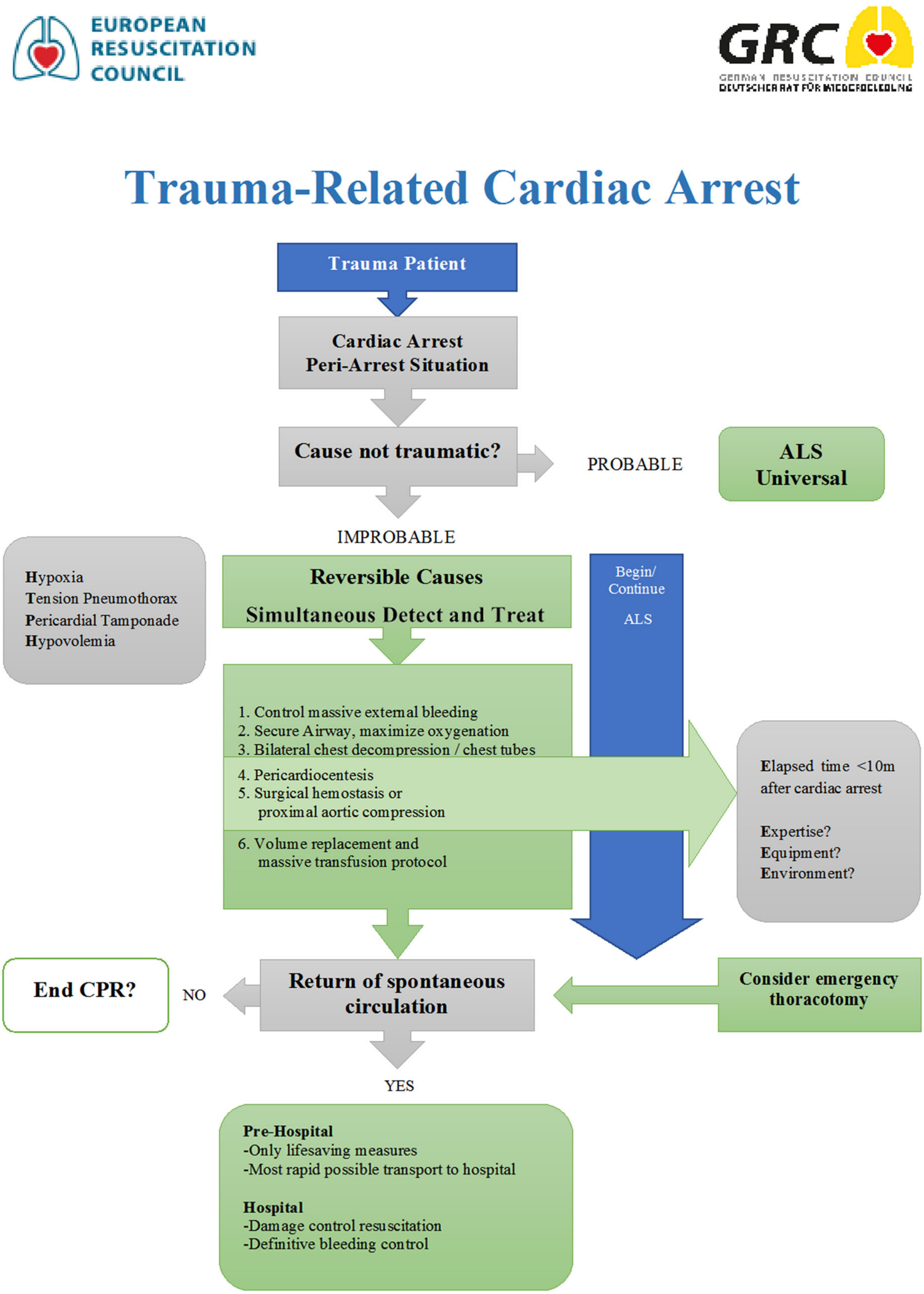
Key recommendation:

2.96	**Recommendation**	**New 2016**
GoR 0	**In individual cases of polytrauma patients with therapy-refractory cardiac arrest, extracorporeal circulation and membrane oxygenation can be considered.**	

Explanation:
Bonacci and Tseng were successful using extracorporeal support procedures (ECLS). Depending on the severity of injury, the procedure can offer adequate hemodynamic support to bridge refractory cardiac arrest and/or pulmonary failure [5, 66]. A successful ECLS program requires adequate structure and a multi-disciplinary team. Equipment, personnel, and additional resources (e.g., sufficient availability of blood products) must be guaranteed around the clock. Combes et al. reported that canulization requires four physicians plus assistants and cardio-technology. The decision to use ECLS should be made carefully, considering all facts. Patients with intracranial hemorrhage (e.g. expanding lesion), or aortic dissection (e.g. heart/vascular injuries) have higher risks during ECLS therapy [2, 12, 45]. Bonacci et al. consider age over 70 years, prolonged hypoxemia, uncontrolled bleeding, and potentially irreversible concomitant conditions as contraindications. Therapy-refractory post-traumatic cardiac arrest was an inclusion criterion. Five of 18 patients survived the hospital admission. ECLS was assessed as a reliable and effective procedure for defined individual cases when resources are available [5].

The evidence table for this chapter is found on page 191 of the guideline report.

Figure 5: ERC/GRC Sequence Algorithm for Traumatic Cardiac Arrest [64, 65]



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2.16 Coagulation System

Note: The following text represents the current state of evidence-based therapy for patients with multiple and severe injuries, which should be applicable to many situations. Nevertheless, it is not possible to address each potential individual case in such a guideline. Thus, in unique circumstances the clinical assessment by an experienced physician can lead to options other than those listed here.

Trauma-Induced Coagulopathy

Key recommendations:

2.97	**Recommendation***	**Modified 2016**
GoR A	**Trauma-induced coagulopathy is an independent clinical picture with clear effects on survival. Thus, coagulation assessment and therapy must be begun at the latest in the emergency department.**	
2.98	**Recommendation***	**Modified 2016**
GoR A	**Basic laboratory assessments of severe trauma must include early and repeated measurement of blood gas analysis, PT, aPTT, fibrinogen, and platelet count as well as blood type determination.**	

2.99	Recommendation*	New 2016
GPP	**When treating severely injured patients in the emergency department, in addition to other diagnostic studies and therapy for trauma-induced coagulopathy, early viscoelastic testing should be performed.**	

* modified according to Spahn et al. 2013

Explanation:

The term "polytrauma" covers a very heterogeneous patient population. Early trauma-related mortality is mostly a consequence of traumatic brain injury (40-50 % of deaths) or massive bleeding (20-40 %). Concomitant coagulopathy markedly increases bleeding [99,142]. The additional coagulation disorder is often a result of the bleeding itself, but is not uncommonly triggered by other trauma and non-trauma-induced changes. Coagulopathy in polytrauma patients (trauma-induced coagulopathy, TIC) has been recognized for several decades [83]. Incidence rates regarding existing coagulopathy at the time of ED admission have been quoted as high as 60 % [43, 109]. Death due to uncontrolled bleeding generally occurs within the first six to twelve hours after trauma, with major distribution within the first one to two hours [105]. Already within a good hour of blunt trauma, there are statistically significant reductions in fibrinogen (factor I) and calcium (factor IV), as well as clotting factors II, V, VII, and X, and a significant increase in factor VIII [21].

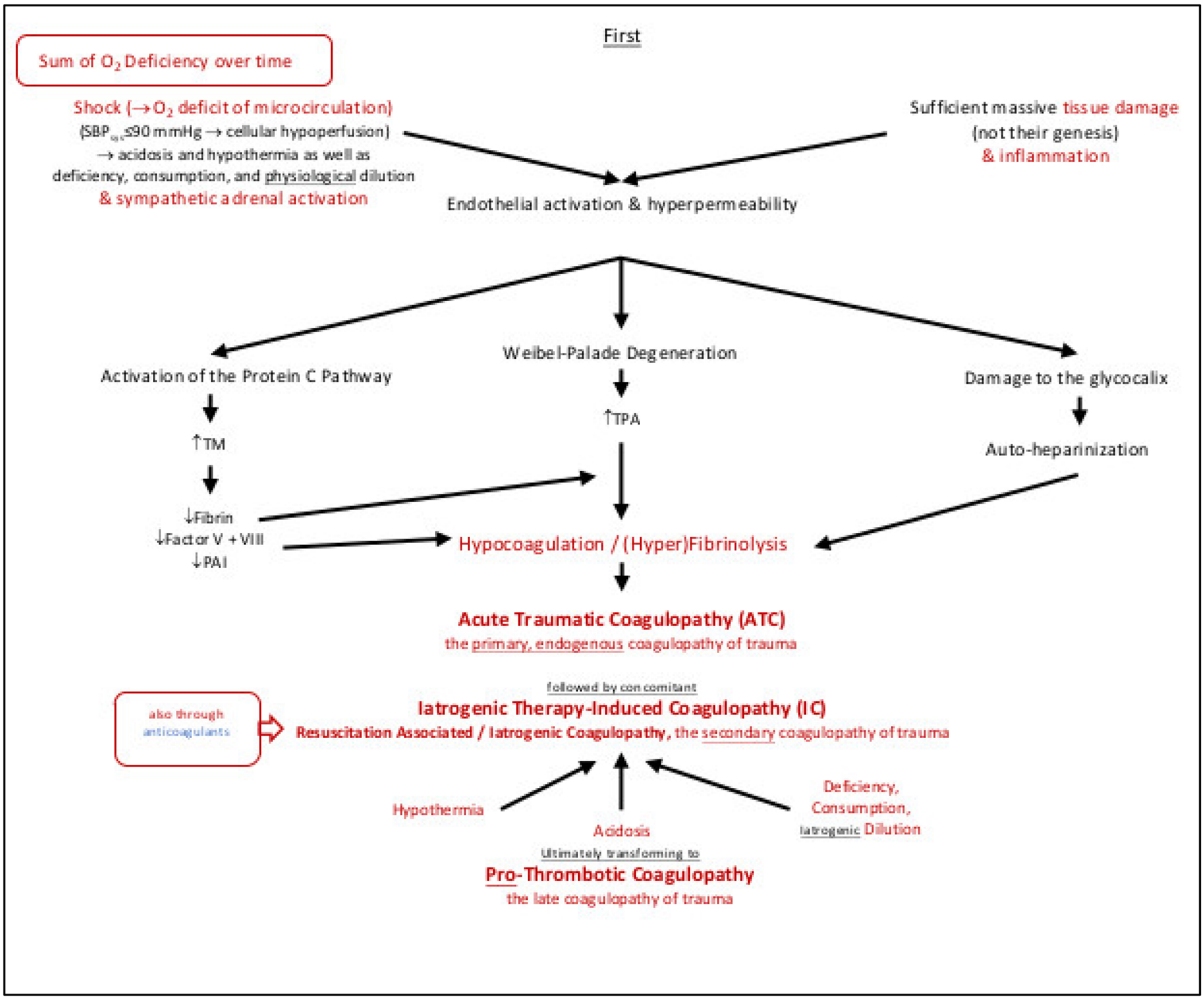
According to the current understanding of TIC, distinctions are made between

- acute trauma-associated coagulopathy (ATC) and
- iatrogenic coagulopathy (IC) as well as the subsequent
- pro-thrombotic coagulopathy.

ATC occurs independently and prior to IC [92, 150].

The following points are important to the current understanding of the development of TIC (Figure 6):

Figure 6: Pathophysiology of Trauma-Induced Coagulopathy (TIC)



Tissue trauma, hypoperfusion, and shock: One of the basic essential mechanisms for the development of acute trauma-associated coagulopathy (ATC) is reduced tissue perfusion on account of shock. In this context, Brohi et al. explained that with tissue hypoperfusion, thrombomodulin is released from the vascular endothelium, forming complexes with thrombin and thus developing an anticoagulant effect [16]. Independent of other factors, direct tissue trauma in combination with hypoperfusion can be the cause of a coagulopathy [107, 109].

Protein C Pathway: Clinical and animal experimental data show that the activation of protein C from tissue trauma combined with hypoperfusion and shock is one of the main triggers for TIC [16]. Activated protein C acts as an anticoagulant in two aspects: First, it splits the peptide bonds of pro-coagulation factors V and VIII, which play roles as co-factors in the activation of factors X and II, and second, it promotes fibrinolysis through the inhibition of plasminogen activator-inhibitor 1 (PAI-1). Cofactor protein S increases the activity of activated protein C. Protein S and factor V are needed to regulate the so-called tenase complexes, which inactivate factor VIII. In addition, protein S is involved in regulation of the prothrombinase complex that inactivates factor V.

Hyperfibrinolysis: High concentrations of thrombin inhibit the activation of plasmin through the activation of TAFI (thrombin activated fibrinolysis inhibitor) and PAI-1. Conversely, TAFI is not activated with low thrombin concentrations. Hyperfibrinolysis has been identified as an important trigger for bleeding-related mortality in polytrauma patients [84]. The magnitude of hyperfibrinolysis appears to correlate with the severity of injury [97]. In patients with verified fulminant hyperfibrinolysis, mortality in the ED is 88 % [144].

Endothelial injury and auto-heparinization: The negatively charged glycocalix covers the vascular endothelium as an anti-adhesive and coagulation inhibiting layer, functioning as a barrier. Tissue trauma, inflammation, hypoperfusion, and sympathetic adrenal activation lead to systemic damage to the vascular endothelium, including the glycocalix, leading to increased vascular permeability. The systemic evidence of various molecules reflects the damage of various endothelial structures: glycocalix: syndecan-1; endothelium: free thrombomodulin (sTM), endothelial growth factor (VEGF); Weibel-Palade body molecules: tissue plasminogen activator (tPA), angiopoietin-2 (Ang-2). The entire endothelial glycocalix contains about a liter of non-circulating plasma with significant quantities of a heparin-like substance. Release into the systemic circulation after the endothelial damage as described above leads to auto-heparinization, as has been proven in trauma patients [127].

Iatrogenic coagulopathy (IC): IC usually occurs with some time delay and can substantially enhance the above-described primary and acute trauma-related coagulopathy. Data from the DGU Trauma Registry (TR-DGU®) was used to show that post-trauma coagulopathy is correlated with administration of higher quantities of intravenous fluids [163]. However, coagulopathy has been reported also in cases where no pre-hospital fluids were given [109]. During hypotension, physiological dilution effects occur through osmosis, with fluid transfer from the interstitial to intravascular space until osmolar equivalence is reached. If each protein is diluted in equal amounts, such as e.g. the intrinsic tenase complex (composed of coagulation factors IXa, VIIIa, and X), the individual factors are proportionately reduced. In addition, coagulation factors are of course also consumed, especially in the acute phase. However, with the combination of consumption and dilution (consumption and dilution coagulopathies), fibrinogen drops out earlier as a substrate for clot formation during the administration of packed red blood cells (pRBCs), as other clotting disorders occur [68].

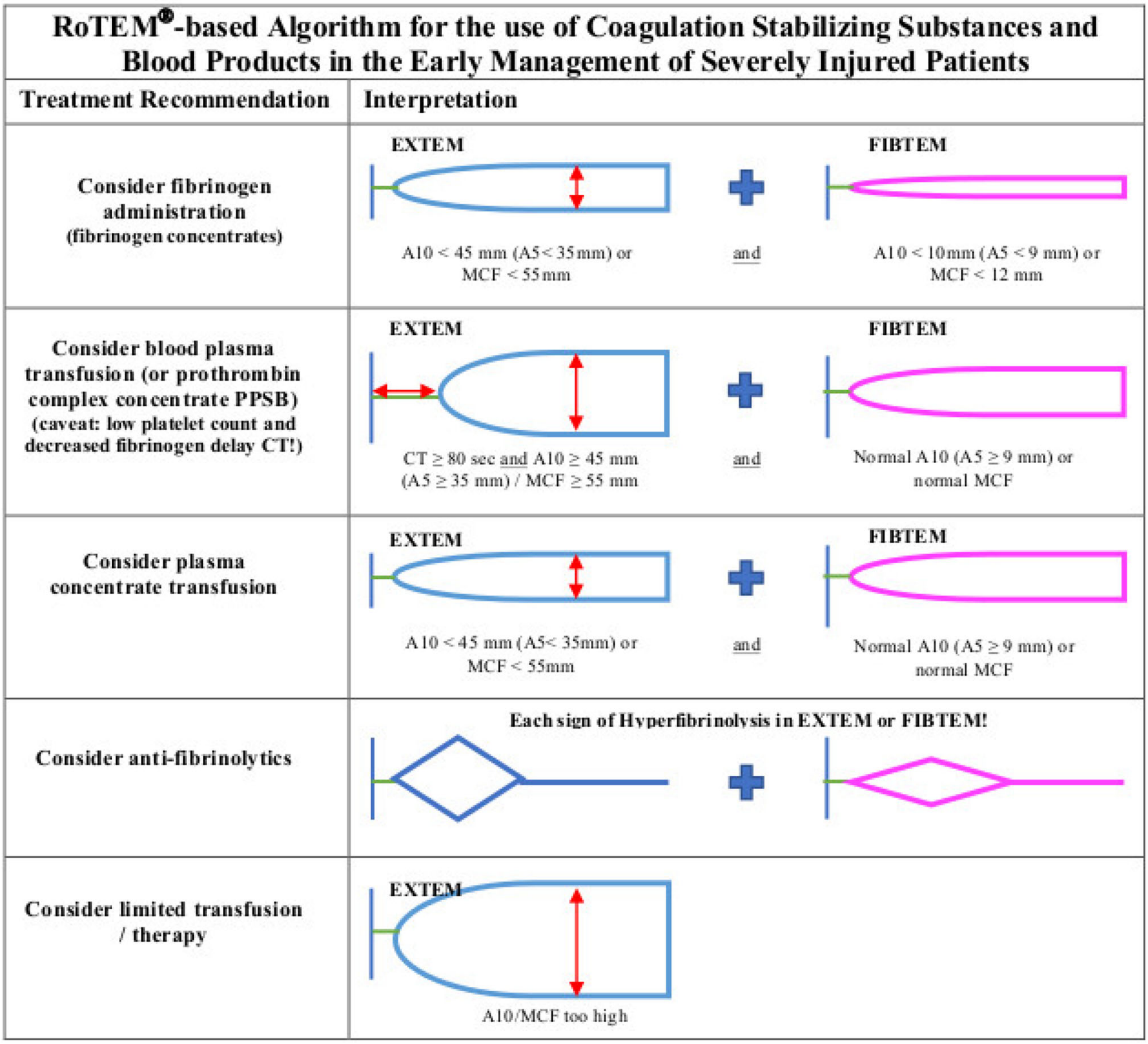
The definition of massive bleeding includes loss of $\geq$ 100% of blood volume within 24 hours, $\geq$ 50% within three hours, and 150 ml/min or 1.5 ml/kgBW/min over 20 minutes [153].

Diagnostic Studies: Although the clinical picture of TIC is characterized by non-surgical, diffuse bleeding from the mucous membranes, serous membranes, and wound surfaces, as well as by bleeding from puncture sites of intravascular catheters and from bladder catheters or nasogastric tubes, there are no generally appropriate laboratory parameters [101].

The "classic" standard coagulation tests (SLTs) are measured at 37 °C, buffered, and with excess calcium in the serum and/or plasma. Thus, acidosis, hypothermia, hypocalcemia, and anemia are not considered, although these factors can have a tremendous impact [46, 102]. Data from the Trauma Registry have shown that prolonged prothrombin time in trauma patients is a predictor for mortality [18, 106, 133]. Here, in addition to PT, documentation of INR is recommended because of better comparability with the baseline values of the Trauma Registry. Recommendation 12 of the third edition of the "European Trauma Guideline" (3rd ET) recommends early, repeated, and simultaneous measurements of PT, aPTT, fibrinogen, and platelets with a GoR 1C [150]. In 2015, Haas et al. published an analysis regarding the evidence of SLTs for the management of coagulopathies. They found only three prospective studies with 108 patients and concluded that there is no good evidence for the use of SLTs for the diagnosis and choice of therapy for coagulopathy. If no other diagnostic options are available, however, the SLTs are preferable to no testing at all [51]. The European [91] and American [4] Associations of Anesthesiology reached the same conclusion in 2013 and 2015, respectively. Thus, sufficient quantities of citrated blood should be taken for SLTs during patient admission to the ED.

Thromboelastography (TE) and Rotational Thromboelastometry (RoTEM): Viscoelastic tests (VETs), i.e. TE and RoTEM, have been increasingly studied for the monitoring of polytrauma patients. In contrast to SLTs, these tests detect not only time until clotting onset, but also the speed of coagulation and the maximum clotting strength. This test procedure can be carried out without delay in the ED. Thus, management decisions can be made more rapidly [131, 138]. Viscoelastic testing offers a time benefit compared to conventional coagulation tests, especially for fibrinogen determination, detection of possible fibrinolysis, prediction of massive transfusions, as well as screening for hemostatic competence and potential complications [30, 35, 53, 108, 143]. Several TEG/RoTEM based algorithms for trauma management have already been published (e.g., [1, 46, 80, 108, 145]). In 2013, the 3rd ET gave a 1C recommendation (strong recommendation, weak evidence) for the use of VET (Rec. 12) and the earliest possible initiation of coagulation assessment (Rec. 23) [150]. In 2014, a systematic review gave a 1B-level recommendation for the trauma population [52]. In 2014, the group of da Luz produced a descriptive review of 38 prospective cohort studies, 15 retrospective cohort studies, and two before-and-after studies of 12 489 patients. The found limited evidence for the diagnosis of earlier TIC using TEG/RoTEM as well as the prediction for blood transfusions and mortality in trauma [33]. In 2015, the UK's National Institute for Health reviewed 39 studies in a "Health Technology Assessment," in which a cost advantage was evident for VETs versus SLTs [168]. The time to occurrence of hyperfibrinolysis and the extent of hyperfibrinolysis on the RoTEM correlated to increased mortality, with a fulminant course having the worst prognosis [108]. A prospective, international multicenter study of 808 patients identified clot amplitude (MCF) at 5 minutes (CA 5) as a valid marker to detect TIC and as a predictor for massive transfusion, with the threshold for EXTEM (CA 5) $\leq$ 40 mm and that of FIBTEM $\leq$ 9 mm (sensitivity 72.7% and 77.5%, respectively). Fibrinogen concentration $\leq$ 1.6 g/l indicated TIC in 73.6 % of cases, and values $\leq$ 1.9 g/l indicated massive transfusion in 77.8 % [55]. In 2015, an international expert group published the results of a formal consensus including the Delphi method to develop a viscoelasticity-based transfusion guideline for the early management of trauma. In this, the recommended VET threshold values were summarized for fibrinogen concentration, platelet concentration, plasma, and PPSB [76, 108]. The RoTEM-based algorithm for the diagnosis and management of multiply injured patients in the ED is shown in Figure 7, and its sources are the German language version of the expert consensus [108] as well as the work cited above by Hagamo et al. [55] (Figure 7).

Figure 7: RoTEM-based Algorithm for Coagulation Management in the ED (modified according to [108]).



When it comes to therapy for coagulopathic bleeding, platelet function is at least as important as the count; despite adequate numbers, the function can be markedly impaired [93]. VETs have only limited ability to assess platelet function, primary hemostasis (inter-platelet and platelet-endothelial interactions), and corresponding anti-platelet medications. For this, impedance aggregometry (e.g., Multiplate®, ROTEM®platelet) is more suitable [93, 149]. The evaluation of platelet function including assessment of medication effects can be carried out with other established laboratory methods (e.g., platelet aggregation measurements with the Born method).

Blood type determination: Early determination of ABO blood type (with antibody testing) on arrival to the ED enables blood type-matched treatment of affected trauma patients. Sufficient quantities of compatible blood preparations can be provided more rapidly when subsequently needed. At the same time, the generally scarce stock quantities of blood group O (Rh+/D+ and Rh-/D-) are not used unnecessarily.

Damage Control Resuscitation

Key recommendations:

2.100	**Recommendation***	**Modified 2016**
GoR B	**In adult patients with active bleeding, the goal should be for permissive hypotension (mean arterial pressure ~ 65 mmHg, systolic arterial pressure ~ 90 mmHg, age-adapted for children) until surgical hemostasis.**	
2.101	**Recommendation***	**New 2016**
GoR B	**For the combination of hemorrhagic shock and traumatic brain injury (GCS <9) and/or spinal trauma with neurological symptoms, MAP should be 85-90 mmHg.**	
2.102	**Recommendation**	**New 2016**
GoR 0	**When central nervous system injury and coronary heart disease are excluded, a lower MAP (~ 50 mmHg) can be aimed for until surgical hemostasis.**	
2.103	**Recommendation***	**New 2016**
GoR A	**Treatment of shock must be controlled with repeated measurements of base excess and/or lactate levels.**	
2.104	**Recommendation***	**Modified 2016**
GoR B	**Cooling of the patient should be avoided with appropriate measures and the goal should be normothermia.**	
2.105	**Recommendation**	**2016**
GoR B	**Acidemia should be avoided and treated with appropriate shock management.**	
2.106	**Recommendation***	**Modified 2016**
GoR B	**Hypocalcemia < 0.9 mmol/L should be avoided and the goal should be for normocalcemia.**	

* modified according to Spahn et al. 2013

Explanation:
Similar to "damage control surgery," where definitive surgical management is temporarily deferred in favor of vital process stabilization, the concept of "damage control resuscitation" has been developed to avoid trauma-induced coagulopathy [9]. Permissive hypotension, prevention of acidemia, hypocalcemia, and hypothermia, as well as the administration of coagulation-promoting medications [151] are all parts of this strategy, which begins as soon as possible [150]. Consistent invasive hemodynamic monitoring as well as the ability to perform rapid, repetitive blood gas analyses is required for the determination of these parameters.

Permissive Hypotension: This term describes two approaches. The first is to tolerate or even strive for lower than normal blood pressure to support thrombus formation. The second is to infuse no more fluid than necessary to ensure adequate end-organ perfusion, and thus, avoid iatrogenic dilution. The correlation between "normal" blood pressure and tendency to bleed after trauma was already recognized at the end of the First World War [22]. The idea of tolerating lower blood pressures according to the palpable radial pulse until time of surgical hemostasis evolved in the military sphere [9].

The basis for clinical application is a study by Bickell et al. from 1994, in which patients with penetrating trauma receiving pre-hospital volume replacement showed higher mortality rates [11]. The accompanying editorial [79] and a large number of readers' responses mentioned flaws in the study design, implementation, and interpretation. Using data from the German Trauma Registry, Maegele et al. found increased incidence of coagulopathy with increasing pre-hospital volume therapy [109]. The effectiveness of restrictive primary volume replacement therapy was first shown in a prospective randomized study in 2011 [119]. In 2013, the 3rd ET gave a 1C level recommendation for a target systolic blood pressure of 80-90 mmHg until surgical hemostasis, when there is no TBI (Rec. 13) [150]. The "palpable radial pulse" was officially recommended for pre-hospital care in 2009 [29], set as target in 2012 [60], and is currently included in the 2015 Resuscitation Recommendations of the European Resuscitation Council (ERC) [158].

Although there is a lack of evidence-based proof in massively bleeding patients, because of pathophysiological considerations and retrospective comparisons, a mean pressure of 65 mmHg or SBP of 90 mmHg are recommended in current review studies. This concept should be considered carefully for older patients and those with known arterial hypertension [150]. While it is indisputable that patients with a combination of hemorrhagic shock with TBI (GCS $\leq$ 8) require higher blood pressure to maintain perfusion (MAP $\geq$ 80 mmHg [150]; SBP $\geq$ 110 mmHg [10]), the combination with spinal trauma and neurology is less clear. The 3rd ET mentions "spinal injury" only in the text of Rec. 13 [150]. Retrospective data analysis [62, 78] and official recommendations [28, 54, 139] suggest MAP of 85-90 mmHg. Patients without CHD and without central nervous system injury can benefit if needed from a lower MAP ($\sim$ 50 mmHg) [119].

To ensure adequate perfusion in spite of permissive hypotension and restrictive volume replacement, repeated measurements of lactate and/or base excess must be carried out, which are prognostically significant [71]. The goal is base excess less than -6 mEq/l [150]. The authors of the 3rd ET give a 1B grade recommendation for the measurement of lactate or base excess, urging caution for lactate measurements in association with alcohol intoxication, and suggest simultaneous measurements of both parameters (text of Rec. 11) [150]. Permissive hypotension is a time-limited option, that must only be maintained until surgical hemostasis [150]. Important in this context is that there is "occult hypoperfusion" at the microcellular level [38], and up to 72 hours (after restoration of the microcirculation, i.e.

adequate macrovascular blood pressure) can pass before the microvascular dynamics allow sufficient cellular perfusion [155].

Warming: Hypothermia ≤ 34°C has significant influence on platelet function and the activity of clotting factors [102]; preservation of normothermia is optimal [150]. To minimize patient cooling, initial fluid therapy must be carried out using warmed infusions [9, 156], and from the ED on, volume replacement must be given exclusively with an infusion warmer with temperatures set to 40-42° C [140, 156]. Both passive (e.g. insulating foil covers, blankets, removal of wet clothing) and active (e.g. replacement of non-warmed with warmed infusions, constant use of heating pads, radiant heaters, hot air blowers) measures are helpful. Both during evaluation and later in the operating room, room temperature should be as high as possible, optimally in the thermoneutral zone, i.e., 28-29°C [140, 159].

The hypothermia-related platelet dysfunction can be partially corrected with an infusion of desmopressin (DDAVP) in the typical dose of 0.3 μg/kg [57, 123, 172].

Acidosis Correction: Acidosis with pH ≤ 7.2 significantly worsens coagulation [20, 102]. Because the main cause of acidosis is hypoperfusion, it will persist until adequate tissue perfusion is restored. Interventions that can enhance acidosis, such as hypoventilation or NaCl infusion, should be avoided [9]. Base excess (BE) also interferes with coagulation [102]; critical thresholds for BE begin between -6 and -10 [173].

Buffering of pH values to ≥ 7.2 alone does not improve the coagulopathy [15], and from a hemostaseologic point of view, is advisable only in combination with administration of coagulation preparations [91, 99]. The 3rd ET repeatedly mentions “acidosis” or “acidemia” as unfavorable and/or as a trigger for “damage control” (Rec. 21); however, it is not further specified [150].

Calcium Replacement: Ionized calcium (Ca^{++}), factor IV of the coagulation cascade, is needed as a cofactor at almost every step of plasma coagulation [102, 103]. The reduction of ionized calcium (Ca^{++}) after transfusion depends on the citrate used as an anticoagulant by the blood bank and is especially pronounced in fresh frozen plasma (FFP). The reduction is even more significant according to increased speed of transfusion, especially with transfusions infused at > 50 ml/min [20]. Calcium monoproducts available in Germany for intravenous use contain variable amounts of calcium ions [100]. This must be considered during replacement. Marked coagulation impairment must be assumed when the ionized Ca^{++} concentration drops below 0.9 mmol/l [99, 102, 103, 150].

Replacement of Coagulation-Promoting Products

In recent years, various studies have explored optimization of therapy with blood products and plasma derivatives in polytrauma patients, and have led to markedly improved survival rates.

Key recommendations:

2.107	Recommendation*	Modified 2016
GoR B	**A specific protocol for massive transfusions and coagulation therapy should be established.**	
2.108	Recommendation*	Modified 2016
GoR B	**In an actively bleeding patient, the decision to transfuse is made individually according to clinical criteria, the degree of injury, extent of blood loss, hemodynamic situation, and oxygenation.** **After stabilization, the goal should be normovolemia and the Hb value should be raised to at least 7-9 g/dl [4.4-5.6 mmol/l].**	
2.109	Recommendation*	New 2016
GoR B	**For cases of (expected) massive transfusions, the indications for FFP should be established and implemented as soon as possible, and otherwise be considered restrictively.**	
2.110	Recommendation	Modified 2016
GoR B	**If coagulation therapy with FFP is carried out in cases of massive transfusions, the target ratio FFP : pRBC : PLT should be 4 : 4 : 1.**	
2.111	Recommendation	New 2016
GPP	**If coagulation therapy is done with factor concentrates for massive transfusions, this should be controlled with appropriate procedures.**	
2.112	Recommendation*	New 2016
GoR A	**For profusely bleeding patients, tranexamic acid (TxA) must be administered as soon as possible, with 1g over 10 min and then followed as needed with an infusion of 1g over 8 hours.**	
2.113	Recommendation*	New 2016
GoR 0	**For profusely bleeding patients, pre-hospital administration of tranexamic acid can be worthwhile.**	
2.114	Recommendation*	New 2016
GoR B	**Administration of tranexamic acid should not be initiated more than three hours after trauma (except in cases of verified hyperfibrinolysis).**	
2.115	Recommendation with majority approval*	Modified 2016
GoR B	**In cases of bleeding, fibrinogen substitution should be performed with thromboelastometric signs of a functional fibrinogen deficit or values of < 1.5 g/l (150 mg/dl).**	
2.116	Recommendation*	New 2016
GPP	**Within 24 hours of hemostasis, decisions must be made regarding the type and beginning of thromboprophylaxis.**	

* modified according to Spahn et al. 2013

Explanation:

Massive Transfusion (and Coagulation Therapy) Protocol (MTP): The term "massive transfusion" generally includes the transfusion of $\geq$ 10 units pRBCs per 24 hours [151]. However, since the highest mortality of multiply injured patients is within the first 2-6 hours, some authors also recommend $\geq$ 10 units pRBCs per 6 hours [82]. At the European level, since 2010, MTP is a mandatory anesthesiology algorithm for the treatment of patients with life-threatening bleeding, which is adapted to local conditions, resources, etc. and must include pre-defined triggers to intervention [115]. It is required by the 2013 perioperative guidelines of the ESA, with a level 1B recommendation (Rec. 5.1.7 [91]), and by the 3rd ET with level 1B and 1C (Rec. 35-37 [150]) recommendations. The Trauma Associated Severe Hemorrhage (TASH) score of the DGU Trauma Registry [173] offers the chance to predict the need for massive transfusion in the civilian sector. It includes the factors systolic blood pressure, hemoglobin (Hb), BE, heart rate, free intra-abdominal fluid, pelvic or femoral fracture, and male gender (0-28 points). Increasing TASH point values can be associated with higher probability for massive transfusion precisely and with good discrimination (area under the curve, AUC, 0.89). Several authors have published and analyzed MT scores, e.g. [14, 27, 122, 126, 164]. According to the 3rd ET, this evidence-based MTP should be adapted to the personnel, logistical, and spatial conditions of the individual hospital and verified in terms of compliance with local protocols (Rec. 35 and 37, GoR 1C) [150]. MTPs can accelerate therapy with blood components and avoid unnecessary discarding of preparations [86]. Better MTP compliance can be associated with better survival [8].

Packed Red Blood Cells (pRBCs): Red blood cells are an essential component of coagulation (overview, for example in [9] or [157]).

There remains no current data from randomized controlled studies regarding the optimal hemoglobin and/or hematocrit levels for coagulation in polytrauma patients. Accordingly, the German Medical Association (*Bundesärztekammer*, BÄK) recommends that the goal should be a hemoglobin concentration around 10 g/dl (6.2 mmol/l), due to the favorable effects of higher hematocrit values on primary hemostasis in cases of massive, acutely bleeding hemorrhages until the time of hemostasis [20]. The 2004 review study by Hardy et al. [58] supports this BÄK recommendation with experimental evidence that hematocrit levels up to 35 % are necessary to maintain hemostasis in bleeding patients. The BÄK emphasizes that Hb value alone is not an indication for transfusion; rather, the capability for physiologic compensation and signs of anemic hypoxia should be considered [20]. Thus, it is possible that in individual cases the goal should be Hb values > 10 g/dl [3, 152]. In cases of massively bleeding patients, it can be necessary to begin transfusion of pRBCs and FFP and plasma derivatives if needed before reaching the Hb target range of 7-9 g/dl due to other causes (e.g. hypoxemia, shock, etc.).

A Cochrane review from 2012 examined 19 studies of 6264 patients (a general patient population, not specific to trauma patients with active bleeding!). The restrictive transfusion trigger (7-9 g/dl) did not appear to affect the rate of side effects (mortality, myocardial infarction, stroke, pneumonia, arrhythmia, thromboemboli) compared to liberal transfusion strategies (9-12 g/dl). The restrictive strategy was linked to a significant reduction of hospital mortality (RR 0.77; 95 CI: 0.62-0.95), but not 30-day mortality (RR 0.85; 95 CI: 0.70 -1.03) [24]. The analysis of 391 985 inpatients found that reduction of average Hb values to 7.6 g/dl prior to transfusion did not significantly worsen the 30-day mortality [136]. Analysis of two studies of 549 patients refusing transfusion showed that mortality is extremely high in post-operative care without transfusion for Hb under 5-6 g/dl. The probability of death increased in patients with post-operative Hb $\leq$ 8 g/dl, calculated around 2.5 times per gram of Hb decrease. There were no deaths in the Hb range of 7-8 g/dl: however, there was a cardiovascular and/or infectious morbidity of 9.4 % [25, 147]. The authors of the 3rd ET offer a grade 1C recommendation (Rec. 17) for a target Hb of 7-9 g/dl after hemostasis; however, the text specifies that the optimal Hb/Hct for stabilization of coagulation in massively bleeding patients is unclear [150]. In the case of TIC, a restrictive transfusion trigger can be unfavorable [114], since significant impairment of coagulation can develop before oxygenation is affected [59]. Similarly, neurological outcomes can be worse when there are lower Hb values after resuscitation (e.g., Hb < 10 g/dl after resuscitation for non-traumatic cardiac arrest + poor cerebral saturation + poor central venous saturation) [3].

A possible correlation between pRBC transfusion with poorer outcomes is intensely debated, and better data through prospective studies is needed [171]. Older publications from the fields of trauma and critical care medicine reported a negative correlation of pRBC transfusion with survival (overview, for example, in [9] or [157]). A current meta-analysis reported that trauma patients appear to benefit from the transfusion of fresh preserves [124]. A current Cochrane analysis of three studies with 120 patients in total yielded no clear benefits from the transfusion of pRBCs collected less than 21 days previous [112]. Observations of earlier studies on the influence of pRBC age on survival may be attributed to the use of non-leukoreduced blood (not permitted in Europe since 2001). The data of multiple prospective randomized studies of seriously ill children and adults (critical care/cardiac surgery) showed no correlation between clinical outcomes and the storage age of transfused packed red blood cells [36, 42, 94, 154].

Other potential consequences from the use of non-leukoreduced blood as reported in international studies are listed here, but cannot be directly correlated to German blood products. In 2009, a retrospective analysis of trauma patients identified an increased risk of 6 % per unit pRBCs for ARDS (adjusted OR 1.06; 95% CI: 1.03-1.10); however, a confounding factor of severe pattern of injury in ARDS patients was not excluded [26]. A retrospective analysis of 1607 children with TBI not requiring surgery found that a transfusion trigger of 8 g/dl can be beneficial in this population [2]. Meta-analysis of observational studies between 1947 and 2012 found a correlation between pRBC transfusion and mortality and/or multi-organ failure/ARDS/ALI and concluded that further interventional studies are needed to clarify how restricted transfusion frequency influences mortality and other effects [128]. A secondary analysis of CRAH-2 data (10 227 transfused of 20 127 patients; observational study, many possible confounding factors) showed that the association between transfusion and mortality in trauma seems to vary according to mortality risk; transfusion seems to lower the risk in high-risk patients, while increasing it in low-risk patients [130]. A correlation between the transfusion of leukoreduced blood products and the occurrence of relevant, transfusion-associated immunomodulation has not been scientifically proven. A meta-analysis of 31 randomized controlled trials with 9813 patients found no benefits or disadvantages regarding mortality, morbidity, and risk of heart attack for liberal (Hb 9-13 g/dl) versus restrictive (Hb 7.0-9.7 g/dl) transfusion strategies [74]. A current study in cardiac surgery patients reported no significant difference in morbidity or health costs between restrictive (Hb $<$ 7.5 g/dl) versus liberal (Hb $<$ 9 g/dl) transfusion triggers [121].

According to the hemovigilance report of the Paul-Ehrlich-Institute (PEI) for Germany from 2013-2014, the most common side effects of pRBCs per million transfused units were: acute transfusion reactions (15.5), transfusion-associated volume overload (8.5), hemolytic transfusion reactions (6.3). Regarding virus transmission, in the years 2012-2014 there was one case of HEV (no cases of Hepatitis A, B, C or HIV) recorded [47].

Fresh Frozen Plasma (FFP): According to the BÄK, plasma therapy is indicated in cases of complex coagulopathy due to overt bleeding and threatened severe bleeding (1C grade of recommendation), to prevent or treat microvascular bleeding. They recommend a rapid initial transfusion of 20 ml/kg BW, but emphasize that greater quantities can be necessary [20]. According to BÄK, treatment of a coagulopathy with plasma alone is not efficient enough because of the need to give large volumes to increase plasma levels, the short half-life of some coagulation factors, and the potential increase in consumption.

In a systematic review of 80 randomized controlled studies, Yang et al. found no consistent evidence for a significant difference between prophylactic and therapeutic administration of FFP; however, the study designs were frequently problematic [169]. In a 2011 matched pair analysis (18 patients each from the DGU and Innsbruck Trauma Registries), Nienaber et al. reported that therapy with FFP alone was associated with a higher rate of multi-organ failure ($p = 0.015$) compared to treatment with factor concentrates (fibrinogen, PPSB); there were also trends towards shorter ventilation times and hospital stays. The overall mortality in both groups was comparable [125]. In 2012, the working group of Mitra reported that a higher ratio of FFP to pRBCs ($>$ 1:2 in the first four hours) in existing TIC (INR $>$ 1.5 or aPTT $>$ 60 sec) is associated with significantly reduced mortality ($p = 0.03$). Conversely, when TIC is absent, high dose FFP has no positive effects and can result in adverse effects and increased costs [117]. There is no good data regarding the effectiveness of other therapeutic plasma products mentioned in the cross-sectional guideline of the BÄK (solvent detergent treated plasma, SDP; methylene blue-treated plasma, MLP; lypophilized human plasma, LHP) in cases of massive transfusions [20].

According to the hemovigilance report of the Paul-Ehrlich-Institute (PEI) for Germany from 2013-2014, the most common adverse effects per million transfused units were: acute transfusion reactions (15.6), transfusion-associated volume overload (3.6), hemolytic transfusion reactions (6.3). Suspicion of viral transmission was not reported in the years 2012-2014. With the reported figures of the year 2014 for FFP, the following additional adverse effects were reported: transfusion-associated cardiovascular volume overload (TACO) 2.41/million units, and transfusion-associated lung insufficiency (TRALI) 1.2/million units [47].

The PROPPR study [73] did not observe higher rates of acute pulmonary failure in the arm with increased plasma administration.

The authors of the 3rd ET recommend avoiding the use of plasma in patients without severe bleeding (Rec. 26.3, GoR 1B) [150].

Ratio of FFP to pRBC: A number of studies have dealt with the FFP : pRBC ratio. Most of these studies had small case numbers and were retrospective (at least for the control population). The idea that pRBCs, FFP, and platelet concentrates (PC) should be substituted in a 1:1:1 ratio is based on the intention to transfuse in as "whole blood" like manner as possible. However, this attempt again only succeeds to a limited extent. Preservatives must be added to the actual components in the banked blood products [49]. Thus, after reconstitution the coagulation activity reaches approximately 65 % of whole blood [5, 49]. Hematocrit and platelet counts are significantly diluted, but remain above the needs for transfusion; in contrast, fibrinogen reaches a concentration of only 1.5 to 1.9 g/l [132]. An increase of each component automatically dilutes the two others. The resulting dilution coagulopathy is proportional to the volume of transfused fluids [23]. In one study, the 1:1 ratio did not correct hypoperfusion or coagulopathy for trauma patients receiving massive transfusions [87].

In 2013, the first prospective multicenter study of this question was published. PROMMTT studied 905 patients receiving $\geq$ 3 blood products (at least 1 unit pRBCs) and analyzed 14 time intervals (minute 31 until day 30). In the first six hours, the mortality of patients receiving FFP : pRBC $<$ 1:2 was 3-4 times higher than those receiving $\geq$ 1:1. After 24 hours, there was no more association. At the median time of mortality probability (2.6 h), only approximately 40 % of patients had received a FFP : pRBC ratio $\geq$ 1:2 [72]. The second prospective multicenter study followed in 2015.PROPPR compared 680 patients expected to receive massive transfusion in FFP:PC:pRBC ratios of 1:1:1 versus 1:1:2. The groups did not differ regarding the primary objectives of the study, mortality within 24 hours (12.7 % in the 1:1:1 group vs. 17.0 % in the 1:1:2 group; difference -4.2 % [95% CI: -9.6 % – 1.1 %]) and within 30 days (22.4 % vs. 26.1 %; difference -3.7 % [95% CI: -10.2 % – 2.7 %]). However, the bleeding-related mortality within 3 hours was significantly reduced in the 1:1:1 group (9.2 % vs. 14.6 %; Difference -5.4% [95% CI: -10.4% —-0.5%]; p = 0.03) [73]. The authors commented that to achieve these effects, crystalloids and/or colloids need to be restricted and blood components should be available within 8 minutes [66]. A prospective study of surgical patients compared the administration of 4 units FFP (group A) versus 2 units FFP plus 2g fibrinogen (group B). Hemostasis was comparably successful, with 21/22 patients in group A and 16/17 patients in group B. There were differences in the coagulation parameters. Prothrombin and clotting Factors VIII, IX, and X were higher in group A; ROTEM parameter fibrin formation was better in B, and thrombin formation was better in A [95]. To avoid dilution coagulopathy, whole blood for massive transfusions (still allowed in many places in the USA but no longer in Germany) has been discussed by individual authors [170]. Fresh blood (preferably still warm) was used in Germany until the 1980s, but this was eliminated due to the lack of rapid infection testing.

Platelet Concentrates (PC): In acute blood loss, platelets are initially released from the bone marrow and spleen; thus, the platelet count drops later on initial hemorrhage. After transfusion, the transferred vital platelets distribute themselves in the blood and spleen, so that the recovery rate in the peripheral blood is only around 60-70 %, sometimes even lower [20]. When the patient is in acute danger because of massive blood loss or because of the localization (intracerebral bleeding), the BÄK recommends platelet replacement when the level falls below 100 000/µl [20]. With the same weak evidence, the 3rd ET also recommends keeping a platelet count $>$ 100,000/µl for massively bleeding patients and those with TBI (Rec. 28.2) [150]. In acquired platelet dysfunction and bleeding tendency, concomitant antifibrinolytic or desmopressin therapies can be indicated [20]. According to BÄK, PC in Germany contains approximately 2 x 10^{11} platelets. Such a PC is available in two preparations: pooled from 4-6 individual donors or as PC apheresis [20]. A German PC then correlates to approximately 4-6 American single-donor PCs as used in the PROPPR study [73]; thus, in cases of massive transfusions, one PC should be substituted after each 4th to 6th pair of pRBC/FFP. Again, it should be emphasized that the platelet count says nothing regarding function [93].

According to the PEI hemovigilance report for 2013/2014, the most commonly reported adverse effects per 1 million transfused PC were: acute transfusion reactions (52.6), suspicion of bacterial contamination (6.2). Regarding virus transmission, in the years 2013-2014 there were two cases of HEV (no Hepatitis A, B, C or HIV) recorded [47].

In summary, trauma patients must be transfused to maintain an individual and sufficient Hb value, with only what is necessary when it is necessary [91].

Note: The main risk in transfusion of blood products remains oversight - more than half of reported cases are due to human error during the transfusion process [13]. The reported rate for mismatched transfusion was 10.19/million units pRBCs, thus, approximately 1:100 000 in 2013/2014 [47]. Therefore, a bedside ABO test should be performed prior to each transfusion, even in cases of emergency (4.3.9 "emergency transfusion") [19]. In addition, batch documentation is mandatory for plasma derivatives; this is required by law according to TFG § 14 (1) and (2) [19].

Fibrinogen: Fibrinogen is a glycoprotein synthesized in the liver, with a long plasma half-life of approximately 3 to 5 days. As an acute phase protein, levels can increase up to 20 times during inflammation and thus, also in association with TIC [113]. Factor I (i.e., fibrinogen) is a clotting substrate essential not only for the formation of the fibrin network but also as a ligand for the GPIIb-IIIa receptor on the platelet surface, and thus, responsible for platelet aggregation. In the context of dilution or severe bleeding, fibrinogen seems to be the most vulnerable of all coagulation factors and is the first to reach its critical concentration [20, 63, 68]. In cases of TIC, fibrinogen is reduced not only by hyperfibrinolysis, but also by increased degradation, acidosis, reduced synthesis as a result of hypothermia as well as loss/dilution [6]. According to BÄK, the minimum plasma concentration following fibrinogen replacement must be 1.0 g/l. The critical threshold where spontaneous bleeding can occur is < 1.5 g/l in cases of heavy bleeding (cross-sectional guideline 7.1.6.2). In adults, generally a single dose of 3-6 g is required. The administration of 3 g of fibrinogen in 3 liters of plasma increases the measured fibrinogen concentration by approximately 1 g/l. In the case of congenital deficiency, the half-life of 96-120h should be considered. In cases of shorter half-life, the fibrinogen concentrations are more frequently controlled (Cross-Sectional Guideline 7.1.7) [20].

Already in 1995, Hiippala [67] determined that in patients receiving colloid infusions, the measurement of "derived" fibrinogens (determined with the PT/INR) as well as those determined with the Clauss method were significantly higher than the actual fibrinogen levels. The BÄK recommends that patients who have received hydroxyethyl starch preparations or dextran and whose fibrinogen levels are determined with the "derived fibrinogen method" should be treated with an intervention threshold of 1.5 g/l instead of 1.0 g/l. When hyperfibrinolysis is suspected, an antifibrinolytic (e.g., 1 g tranexamic acid) should be given beforehand [20].

The following presents studies regarding fibrinogen replacement in acute bleeding and controls, grouped according to size and profile and thus, enabling conclusions based on the study results. Recently, Hagemo et al [41] published a multicenter study (International Trauma Research Network, INTRN) of 808 patients from four trauma centers in England, Denmark, and Norway (2007-2011) with the goal to reevaluate smaller cohort studies to characterize TIC and to evaluate the threshold values for fibrinogen concentrations (VET); they found that MT was necessary in 6.1 % of cases, and that TIC was present in 11 %. The most important conclusions came in addition to the results stated above (VET as a valid method for threshold determination of fibrinogen concentration), which confirmed the results of earlier cohort studies that the Clauss method determinations were comparable with the best parameters of VET, and that future studies should be planned to test coagulation therapy guided by VET in trauma. Hagamo et al. published a multicenter study of 1133 patients treated within three hours in a trauma center. They examined the initial fibrinogen concentrations (prevalence of hypofibrinogenemia), as there is still little evidence regarding the use of fibrinogen in the acute phase. In 8.2 %, the fibrinogen concentration was ≤ 1.5 g/l, and in 19.2 %, it was < 2.0 g/l. With initial concentrations under 2.29 g/l, there was a marked increase in the 28-day mortality. The average initial fibrinogen concentration of 28 day survivors was 2.68 g/l and it was 1.95 g/l in non-survivors ($p<0.001$). With fibrinogen concentrations under 2.29 g/dl (95% CI: 1.93-2.64), there was a 90 % reduction in mortality for each unit increase of fibrinogen concentration, although the results must be interpreted cautiously due to the large confidence intervals. The authors recommended that these results be validated using interventional studies with fibrinogen concentrates [56]. A larger prospective cohort study of 517 patients from Rouke et al. was devoted to the course of fibrinogen concentrations, monitored with VET and Clauss method determination. The blood samples were collected at admission and after transfusion of four units pRBCs. Low fibrinogen levels on admission were independently associated with ISS ($p = 0.002$), shock ($p = 0.002$), and the quantity of pre-hospital volume given ($p < 0.001$). Fibrinogen concentrations varied significantly between non-survivors after 24 hours (1.1 g/l vs. 2.3 g/l, $p < 0.001$) and after 28 days (1.4 g/l vs. 2.4 g/l, $p < 0.001$) [137]. Other studies are mostly monocentric cohort studies examining fibrinogen replacement in smaller patient groups. When a concentration of < 2 g/l is used as indication for fibrinogen substitution (average 2 g, range 1-5 g), Fenger-Eriksen et al. found significant reductions in the need for pRBCs ($p < 0.0001$), FFP ($p < 0.0001$), and PC ($p < 0.001$) as well as blood loss ($p < 0.05$) in 35 heavily bleeding adult patients [40]. In a retrospective analysis of 30 massively bleeding patients with hypofibrinogenemia (fibrinogen < 1.5 g/l) of varying etiologies, Weinkove et al. raised the level from 0.65 to 2.01 g/l (Clauss method) with administration of 4 g fibrinogen (median; range 2-14 g) [166]. In a retrospective analysis, Farriols Danes et al. found that patients (n = 81) with acute, bleeding-related hypofibrinogenemia (substitution below 1 g/l) react with a marked increase on fibrinogen replacement and, in contrast to patients with chronic fibrinogen deficiency ($p = 0.314$), they have a significantly better 7-day survival rate ($p = 0.014$) [34]. In an in vitro study, the blood of subjects (n = 6) was diluted 1:5 with NaCl 0.9 % solution. To optimize the rate of clot formation, a fibrinogen concentration > 2 g/l was necessary. The results of this in vitro study cannot be directly transferred to a clinical situation, and must be prospectively verified with clinical studies [130]. Matched-pair analysis (registry study; n = 294 patients per group) with data from the DGU Trauma

Registry found that patients receiving fibrinogen concentrates between admission and the ICU showed significantly decreased 6-hour mortality (10.5 % vs. 16.7 %, p = 0.03), prolonged time until death, but also an increased rate of multi-organ failure, although the overall mortality during admission did not vary compared to patients receiving no fibrinogen (28.6% vs. 25.5%, p = 0.40). These results should be verified with prospective, randomized controlled studies [161]. In a prospective cohort study of 144 patients with ISS > 15 by Innerhofer et al., 66 patients were treated with fibrinogen and/or PPSB concentrate (CF group) and 78 patients received additional FFP (FFP group). Patients treated with fibrinogen concentrates and/or PPSB received significantly less pRBCs and PC than those receiving additional FFP (pRBCs median 2, range 0-4 units vs. median 9, range 5-12 units; PC median 0, range 0-0 units vs. median 1, range 0-2 units; $p < 0.001$). In addition, patients of the CF group showed less multi-organ failure (18.2% vs 37.2%, p 0.01) and sepsis (16.9% vs. 35.9 %, p = 0.014) [77]. In a prospective in vitro study comparing 63 trauma versus 63 critically ill non-trauma patients, thrombopenia $< 150 \times 10^9$/l and fibrinogen concentration < 2 g/l were the only factors associated with enhanced bleeding tendency, according to special measurements with the TEG (MA) [70]. A retrospective analysis evaluated fibrinogen concentrations of 290 patients on admission (3-year period, level I trauma center). In this retrospective analysis of 290 blunt trauma patients, fibrinogen concentration < 2 g/l on admission was an independent predictor for 7-day mortality [88]. A retrospective analysis of 260 trauma patients (average ISS 26 ± 13) with massive transfusions (≥ 10 units pRBCs within the first 24 hours) divided patients into three groups according to fibrinogen concentration on admission: normal (≥180 mg/dL), abnormal (≥101 to < 180 mg/dL), and critical (≤100 mg/dL). A value ≤ 100 mg/dl led to significantly increased 24h mortality (adjusted OR 3.97; adjusted p = 0.013; $R^2 = 0.141$), significantly increased hospital mortality, and was the most important independent predictor for mortality (p = 0.012). The impact of a fibrinogen replacement strategy requires prospective evaluation [75]. There is evidence that a fibrinogen concentration ≥ 2 g/l can be advisable in trauma patients with acute bleeding, but there are no large prospective RCTs. Once the acute bleeding is controlled, the fibrinogen concentration should not drop below 1.5 g/l. The costs for fibrinogen concentrates are not reimbursed by the state health insurance for every case, especially in emergency therapy. Currently (DRG 2016), fibrinogen cannot be billed through additional charges in polytrauma patients (exceptions: congenital coagulation deficiencies, exceeding a total sum of clotting factors). For cost reasons and because there is a lack of randomized multicenter studies proving a survival benefit at higher target thresholds for fibrinogen replacement, the previous threshold of 1.5 g/l for fibrinogen replacement was maintained, and the 1C recommendations of the 3rd ET (Rec. 27 [150]) and the ESA (Rec. 7.1.2 [91]) of 1.5-2 g/l were not adopted.

There is very little data currently available regarding adverse effects of fibrinogen (concentrates). In a systematic review of studies from years 2000-2013, Aubron et al. found no increased rates of adverse effects in trauma patients [6]. The retrospective evaluation by the manufacturer, over a period of 27 years, yielded allergic reactions (1 : 32 600 doses), possible thromboemboli (1 : 23 300 doses), and possible virus transmission (1 : 21 000 doses), in addition to the problem of “underreporting” [37, 148]. Here the results of larger studies are awaited. Therefore, when using fibrinogen, the instructions of the manufacturer and the BÄK [69] should be complied with and the initial dosing of fibrinogen followed. Because fibrinogen has a long half-life (approximately 3-4 days) and there is a risk of accumulation at high or repeated doses, the risk of thromboemboli can be increased. Especially in cases of disseminated intravascular coagulation, which is associated with TIC, it is important to ensure balanced treatment with blood and plasma derivatives.

In addition to SLTs, e.g. viscoelastic tests are appropriate to guide the replacement of factor concentrates [76, 108, 116].

Prothrombin Concentrates (PPSB): Mixed preparations of vitamin K dependent factors prothrombin (FII), proconvertin (FVII), Stuart factor (FX), and anti-hemophilia factor B (FIX) as well as protein C, protein S, and protein Z do not include fibrinogen, FV, or FVIII [141], and are only standardized regarding factor IX content, so that the contents of the other clotting factors above can fluctuate widely [20]. The PPSB preparations available today contain practically no activated clotting factors or activated protein C or plasmin, so that undesirable effects such as thromboembolic events, disseminated intravascular coagulation, and/or hyperfibrinolytic bleeding are very improbable, even when given in large amounts [20]. Thromboemboli reported in the past were most likely due to a marked excess of prothrombin in some PPSB concentrates that are no longer available on the market today [50]. Therefore, general replacement of anti-thrombin is no longer necessary [20].

The main indication for PPSB is the elimination of vitamin K antagonist activity. This indication has been validated in many studies; for patients taking Vitamin K antagonists, the BÄK [20] recommends pre-operative administration of PPSB for bleeding prophylaxis. In TIC, the prothrombin complex deficiency can be so pronounced that FFP administration must be supplemented with PPSB

[20, 141]. In cases of severe bleeding, the BÄK recommends an initial bolus of 20-25 IE/kg BW; significant individual variations in effectiveness must be considered [20]. The weak 2C recommendation of the 3rd ET includes a note that PPSB administration is coupled to the thromboelastometric signs of delayed initiation of coagulation (Rec. 31.2 [150]). Thus, after PPSB administration, careful laboratory monitoring of coagulation should be performed. Joseph et al. compared the administration of FFP alone or in combination with PPSB in 252 polytrauma patients (median ISS 27) [81]. Supplemental PPSB resulted in faster normalization of INR (394 vs. 1050 min; p = 0.001), reduced consumption of pRBCs (6.6 vs. 10 units; p = 0.001) and FFP (2.8 vs. 3.9; p = 0.01) as well as reduced mortality (23 vs. 28%; p = 0.04). The higher costs of PPSB ($1470 $\pm$ 845 vs. $1171 $\pm$ 949; p = 0.01) were offset by markedly reduced transfusion costs ($7110 $\pm$ 1068 vs. $9571 $\pm$ 1524; p = 0.01). In trauma patients, PPSB administration leads to a sustained and pronounced increase in endogenous thrombin potential as well as reduced anti-thrombin levels; both can cause an increased risk for thromboembolic events [146]. These adverse effects have also been reported in association with the rapid suspension of vitamin K antagonist activity during surgery. In a retrospective review study with data from twelve hospitals (n = 193), Hedges et al. reported that eight patients (approximately 4 %) suffered acute venous thromboemboli after PPSB [64]. The results of this study are transferable to trauma patients only in a limited fashion.

Anti-fibrinolytics: Hyperfibrinolysis appears to be more common in polytrauma patients than previously assumed (just under 20 % [84, 142] up to 60 % [43, 109]); its extent correlates with injury severity [97] and increasing mortality [144]. In children with multiple injuries, hyperfibrinolysis seems to be more commonly present on admission [104]. Prompt diagnosis of hyperfibrinolysis and also the effectiveness of antifibrinolytic therapy is possible only with thromboelastography/thromboelastometry [97, 144]. Administration of antifibrinolytics must be included in the overall coagulopathy management concept, since in hyperfibrinolysis there is often a heavy consumption of fibrinogen up to and including complete defibrination of the patient [17]. This fibrinogen deficiency must be balanced after the hyperfibrinolysis is resolved; in other words, in suspected hyperfibrinolysis, the anti-fibrinolytic should be applied before fibrinogen [20]. Tranexamic acid is a synthetic lysine analogue that inhibits the conversion of plasminogen to plasmin by blocking the binding of plasminogens to the fibrin molecule.

CRASH-2 was a prospective randomized placebo-controlled study performed in 274 hospitals in 40 countries to examine the effects of early administration of TxA to trauma patients on mortality, thromboembolic events and the need for transfusion [32]. Adult trauma patients (> 16 years) with significant hemorrhage (systolic blood pressure < 90 mmHg or pulse > 110/min) were included according to the “uncertainty principle,” i.e., when there was no clear (contra-)indication for TxA. Accordingly, TxA (or placebo) was infused as an initial bolus (1 g over ten minutes) followed by 1 g over 8 hours. After the inclusion of 10 060 patients (TxA group) and 10 067 patients (placebo), the primary endpoint of mortality was reduced with TxA (14.5 % vs. 16.0 %, p = 0.0035), absolute mortality risk reduction (AMRR) = 1.5 %: number needed to treat (NNT) 67. Bleeding-related mortality was also reduced (4.9 % vs. 5.7 %, p = 0.0077, NNT 119). There was no significant variation in the secondary endpoints of thromboembolic events (1.7% vs. 2.0%, p = 0.084), need for surgical intervention (47.9% vs. 48.0%, p = 0.79), or transfusion of blood products (50.4% vs. 51.3%, p = 0.21). Despite the immense effort required for this study, no data regarding laboratory parameters, injury severity (e.g., injury severity score), or administration of other coagulation-active products/substances was documented. Although the study findings yield a recommendation level GoR A, one major criticism is that the majority of participating hospitals are located in developing countries where one cannot assume modern management of severely injured patients. In addition, the mechanism of action for TxA remains unclear; hemorrhage was not the main problem of the study population, since only 50.4 % of patients received blood transfusions (median 3, range 2-6 units pRBCs) and since of 3076 mortalities (15.3 %), only 1063 were bleeding-related. MATTERs, a retrospective study in the military sphere, found that treatment with 1 g TxA, followed as needed with one further gram, yielded an AMRR of 6.5 % (NNT = 15) for the patients overall and an AMRR of 13.7 % (NNT = 7) for massive transfusion patients [120]. Neither CRASH-2 nor MATTER were able to demonstrate reduced need for transfusions in trauma patients (in contrast to studies of a perioperative setting, e.g. [85]). Based on the CRASH-2 data, the 3rd ET gave a 1A recommendation for the earliest possible administration of 1 G TxA over 10 min, followed by 1 g over 8 h, for all bleeding trauma patients (Rec. 24.1 [150]). Smaller studies of trauma patients with measurements of clotting parameters have not been able to repeat the reduced mortality of CRASH-2 [61, 160].

A secondary exploratory analysis of the CRASH-2 data revealed that the survival benefit was only evident when the therapy was initiated in the first three hours after trauma (Hazard Ratio HR $\leq$ three hours = 0.78; 0.68-0.90; HR > three hours = 1.02; 0.76-1.36). The start of TxA administration within the first three hours also reduced the risk of bleeding-related death by 28 %, while administration after three hours appears to correlate with higher mortality [31, 135]. From this comes the recommendation to forego later administration (more than three hours after trauma), except when there is laboratory evidence of hyperfibrinolysis. The recommendation for pre-hospital administration has also been extrapolated from the CRASH-2 data; sufficient studies are not yet available for this. For these reasons, the 3rd ET gives a 1B recommendation for administration within 3 hours (Rec. 24.2 [150]).

Desmopressin (DDAVP): Desmopressin (1-deamino-8-D arginine vasopressin) is a synthetic vasopressin analogue. Desmopressin (e.g. Minirin®) causes non-specific platelet activation (increased expression of the platelet GpIb receptor [129]), and releases von Willebrand factor as well as FVIII from the liver sinusoidal endothelium, thus improving primary hemostasis [44]. The main indication for its use is for perioperative therapy of von Willebrand disease. In TIC, von Willebrand disease can be acquired, i.e. impaired platelet function as a result of particular medications (e.g., ASS, heparin, ADP receptor antagonists/thienopyridine derivatives), acidosis, or hypothermia [44, 150]. After i.v. administration, maximal effects occur only after approximately 90 minutes [98]. Repeated administration can lead to release of tissue plasminogen activator (tPA) and thus, to hyperfibrinolysis. Thus, some authors recommend simultaneous application of tranexamic acid on repeat administration [98]. No controlled studies of trauma patients are available.

From a pathophysiological perspective, a trial dose of DDAVP can be considered in patients with suspected platelet dysfunction as a result of acquired von Willebrand disease, at a dosage of 0.3 μg/kg BW over 30 minutes (Rec. 30 [150]).

Factor XIII: In the presence of calcium ions, FXIII causes covalent fibrin cross-linking. This produces a three-dimensional fibrin net that leads to definitive wound healing [20]. Factor XIII is not detected with the general PT/INR and aPTT (activated partial thromboplastin time) tests, as these only measure the onset of fibrin formation, not fibrin cross-linking [20].

An acquired deficiency is not uncommon and in TIC, may arise from increased turnover (increased blood loss, hyperfibrinolysis) and consumption (during large operations). In patients with existing clotting activation, e.g. from a tumor, there may be a severe FXIII deficiency that leads to massive hemorrhage as a consequence of trauma or surgical intervention [89]. There are no randomized studies of trauma patients.

When rapid FXIII testing is not available, especially in cases of severe, acute bleeding, blind administration of FXIII should be considered [20]. Prior to bleeding control, a possible initial dose of 15-20 IE/kgBW is recommended. Because the concentrate is produced from human plasma, a residual risk for infection cannot be excluded. However, it should be noted that Factor XIII, like fibrinogen, has a long half-life and can accumulate with repeated doses.

Recombinant activated Factor VII (rFVIIa): The approval of rFVIIa is limited to bleeding in cases of hemophilia (antibodies against factors VIII or IX), Glanzmann's thrombasthenia (congenital dysfunction of the platelet GPIIb-IIIa receptor), and congenital factor VII deficiency. The rFVIIa binds to activated platelets in a supra-physiological dosage and causes a "thrombin burst" that leads to the formation of an extremely stable fibrin clot [45]. The rFVIIa also enables thrombin generation on activated platelets independent of tissue factors.

A number of clinical case studies have portrayed unapproved uses. Undesired side effects in the form of thromboembolic events in the arterial and venous vasculature and/or in perioperative or traumatically damaged vessels have been reported particularly in cases of "off-label" use [20]. Registry data show an incidence of almost 9 % in trauma [174]. Matched-pair analysis with data of the German Trauma Registry concluded that the administration of rFVIIa in trauma patients does not reduce the need for blood products or decrease mortality, but is associated with cumulative multi-organ failure [162]. In 2005, Boffard et al. [12] studied the effectiveness of 400 μg/kg BW rFVIIa (after the 8th unit pRBCs, with a primary dose of 200 μg/kgBW followed by 100 μg/kgBW each at 1 and 3 hours) versus placebo as adjuvant therapy in 143 blunt and 134 penetrating trauma patients. In blunt trauma, there was a significant reduction of transfused pRBC units (calculated decrease of 2.6 units, $p = 0.02$) and the need for transfusion of $\geq$ 20 units pRBCs (14 % vs. 33 %; $p = 0.03$). In penetrating injuries, there was a trend in this direction for both parameters. Neither decreased mortality nor increased thromboembolic events were observed.

The effectiveness of rFVIIa is linked to a series of requirements that should be met prior to application: a fibrinogen value $\geq$ 1.5 g/dl, Hb $\geq$ 7 g/dl, platelet count $\geq$ 50 000 /μl (better $\geq$ 100 000/μl), ionized calcium $\geq$ 0.9 mmol/l, core temperature $\geq$ 34 °C, pH $\geq$ 7.2 as well as exclusion of hyperfibrinolysis or heparin effect [20, 45]. A widespread standard dose for off-label use is 90 μg/kg BW [39, 165].

In its guideline, the BÄK refers to the review article by Mannucci et al. [111]. Its conclusion is that rFVIIa is not a panacea, but it is effective for patients with trauma and excessive bleeding that do not respond to other therapeutic options. One application, for use only after conventional therapies have been unsuccessful, is also being promoted [91, 150]. The current manufacturer's information from the company NovoNordisk (December 2013) recommends that rFVIIa not be used outside of approved indications, due to the risk of arterial thrombotic events in the range of ≥ 1/100 to < 1/10.

Thromboprophylaxis: TIC has a third, late stage: the prothrombotic coagulopathy predisposing for venous thromboembolism [7, 23, 110]. While it is relatively clear that the early stages of TIC are not histologically identical to disseminated intravascular coagulation (DIC) because of the lack of intravascular clots [134], later stages overlap [48]. The optimal time point to begin thromboprophylaxis is often difficult to discern; one study showed increased mortality when this occurred after 24 hours [69]. The authors of the 3rd ET give a 1B recommendation that says to begin pharmacological thromboprophylaxis within 24 hours of hemostasis (Rec. 34.2 [150]). In this context, the AWMF-S3 Guideline 003/001 "Prophylaxis of Venous Thromboembolism (VTE)" from October 2015 was referenced.

In summary, the age of "personalized medicine" applies also for trauma patients, who should be transfused, infused, and monitored in the best possible way according to individual and sufficient Hb and platelet values as well as sufficiently good clotting functions (if needed, with the use of clotting activators and/or inhibitors), with only what is really necessary when it is necessary [91]. Prospective randomized controlled studies are needed urgently to clarify the issues that remain open.

Summary Table

The escalating medical options for coagulopathic bleeding described above can be summarized as follows (modified according to [99, 150]).

Table 15: Escalating medical therapy options for coagulopathic bleeding (Summary)

1. Stabilization of the general conditions (prophylaxis and therapy!)	Core temperature **≥ 34°C** (normothermia if possible) pH value ≥ **7.2** ionized Ca^{++} concentration > **0.9 mmol/l** (normocalcemia if possible)
2. Earliest possible inhibition of potential (hyper) fibrinolysis (always before fibrinogen administration!)	**Tranexamic acid** initially 1 g (15-30 mg/kgBW) or 1 g in ten min + 1 g over 8h
3. Replacement of oxygen carriers	**pRBCs:** once stabilized, raise Hb to at least 7-9 g/dl [4.4-5.6 mmol/l]
4. Replacement of clotting factors (for existing tendency for severe bleeding)	**FFP** ≥ 20 (rather 30) ml/kgBW (only for [expected] massive transfusion)
In patients requiring massive transfusions or in bleeding-related, life-threatening shock and in whom coagulation therapy will be given by administration of FFPs during massive transfusion, the goal should be a proportion of 4 FFP : 4 pRBC : 1 PC.	and **fibrinogen** (2-)4(-8) g (30-60 mg/kgBW, target: ≥ 1.5 g/l, higher if needed, e.g. peripartum) if needed, 1-2x **PPSB** initial dose (1000-2500 IU) (20-30 IU/kgBW) and if needed **FXIII** 1250 IU (30 IU/kgBW)
and (in suspected thrombocytopathy) increased platelet adhesion to the endothelium and release of von Willebrand factor and FVIII from liver sinusoids (→ agonist for vasopressin receptor type 2)	**DDAVP = desmopressin** 0.3 μg/kgBW over 30 min ("1 vial per 10 kg BW over 30 min")
5. Substitution of platelets for primary hemostasis	**Platelet Concentrates** (Apheresis/Pool PC): Target for transfusion-dependent bleeding and/or TBI: > 100 000/μl
6. If needed, thrombin burst with platelet and clotting activation (pay attention to the requirements! Off-label use!)	In individual cases and if all other treatments are unsuccessful, if needed, **rFVIIa** initial dose 90 μg/kgBW
Within 24 hours of hemostasis	**make decisions regarding the type and initiation of thromboprophylaxis**

Bleeding on anti-coagulation: Bleeding in anticoagulated polytrauma patients is a recurrent problem, especially when no history can be collected. While the effects of vitamin K antagonists and heparin are readily measurable with PT/INR and/or aPTT tests, this is much more difficult with direct, non-vitamin K antagonist oral anticoagulants (NOAC), since the specific tests generally require more time. A discriminating discussion of this topic is beyond the scope of this guideline. It is advisable to discuss with the individual hospital laboratory regarding the sensitivity of respective laboratory tests for NOAC. The following Table 16 can be used as a rule of thumb for NOAC assessment in the ED [65, 90, 118]:

Table 16: NOAC Assessment in the ED (rule of thumb)

Dabigatran (Pradaxa®)	normal aPTT and normal PT → probably no relevant plasma levels;
Rivaroxaban (Xarelto®)	sensitive (e.g., Neoplastin Plus®) PT/INR > 80% or normal anti-Xa activity → probably no relevant plasma levels;
Apixaban (Eliquis®)	minimal influence on PT/INR and aPTT; specific anti-Xa activity → more exact plasma levels;
Edoxaban (Lixiana®)	PT/INR presumably and aPTT questionable sensitivity (which assay?); specific anti-Xa activity → more exact plasma levels;

The following Table 17 lists the options to counter common anticoagulants [41, 65, 90, 96, 118, 167]:

Table 17: Options to Oppose Common Antithrombotics

	Time to normal hemostasis after therapeutic dose	Antidote	Remarks
Vitamin K antagonists	Phenprocoumon = Marcumar®: 8–10 d Warfarin = Coumadin®: 60–80 h	**Vitamin K** = Konakion® 20 mg i.v. (max 40 mg/d, rate approx. 1 mg/min) or 2-3 mg p.o.	Vitamin K = Konakion® i.v.: delayed effect 12–16 h (begins already in 2 h) Vitamin K = Konakion® p. o.: delayed effect in 24 h
		PPSB (20-25 IU/kg or (PT_{now}–PT_{target}) x kg BW)	PPSB i.v. immediate effect
Heparin	3-4 h	**Protamine (25-30 mg): immediate effect**	1 mg (= 100 U) per 100 anti-Xa units given in the previous 2-3 h
LMW Heparin (Certoparin = Mono-Embolex®, Dalteparin = Fragmin®, Enoxaparin = Clexane®, Nadoprarin =Fraxiparin®, Reviparin =Clivarin®, Tinzaparin =Innohep®)	12-24 h	**Protamine** (25-30 mg): immediate partial effect	only partial; 1 mg (= 100 U) per 100 anti-Xa units given in the previous 8 h (possible 2nd dose with 0.5 mg)
Pentasaccharide/subcutaneous Xa inhibitors	Fondaparinux = Arixtra® 24–30 h	**probative: rFVIIa** = NovoSeven® (90 µg/kg)	experimental
Oral Xa Inhibitors (Rivaroxaban = Xarelto®, Apixaban = Eliquis®)	usually within 12 h (→ then thromboplastin time [PT/INR] normal or absent anti-Xa effect [NMH testing])	**no reliable antidote**	Activated charcoal (30-50g) if Xa-inhibitor intake < 2h
		Adjuvants: DDAVP = Minirin® (0.3 µg/kg i.v.) plus **Tranexamic acid** (TxA = Cyclokapron®; 3x 1 g or 20 µg/kg i.v.)**; probative: PPSB** (25–50 IU/kg i.v. or (PT_{now}–PT_{target}) x kg); if needed **activated PPSB** = FEIBA® (50–100 IE/kg i.v.; max. 200 IE/kg/d) or **rFVIIa** = NovoSeven® (90-100 µg/kg i.v.)	experimental (DDAVP in acquired von Willebrand disease)
Direct oral thrombo-inhibitors (Dabigatran = Pradaxa®)	usually within 12 h (→ then thrombin time [TT] normal to slightly prolonged)	specific antidote: **Idarucizumab=**Praxbind®; 2x 2.5 g i.v.	if needed, dialysis (high flux filter); Caveat: rebound at the end of dialysis? Activated charcoal (30-50g) if the IIa inhibitor taken within 2(-6) h
		Adjuvants: DDAVP = Minirin® (0.3 µg/kg i.v.) plus **Tranexamic acid** (TxA = Cyclokapron®; 3x 1 g or 20 µg/kg i.v.)**; probative: PPSB** (50 IU/kg i.v., if needed + 25 IE/kg); if needed **activated PPSB = FEIBA**® (50–100 IE/kg i.v.; max. 200 IE/kg/d) or rFVIIa **= NovoSeven**® (90-100 µg/kg i.v.)	experimental (DDAVP in acquired von Willebrand disease)
Aspirin	5–10 d	**DDAVP** = Minirin® (0.3 µg/kg i.v.) and/or **platelet concentrates** (target: > 80 000/µl); effect in 15-30 min	Hospital-dependent
Thienopyridine = ADP Antagonists (Clopidogrel = Iscover® = Plavix®, Prasugrel = Efient®)	1–2 d	**Platelet Concentrates (goal: > 80 000/µl), if possible with** DDAVP **+ Minirin**® (0.3 µg/kg i.v.); effect in 15-30 min	Hospital-dependent

Reversal of antithrombotics must be well considered, as it inevitably increases the risks of thromboembolism!
The evidence table for this chapter is found on page 198 of the guideline report.

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2.17 Interventional Hemorrhage Control

Key recommendations:

2.117	**Recommendation**	**2011**
GoR B	**Embolization should be performed if possible on patients who can be hemodynamically stabilized.**	
2.118	**Recommendation**	**Modified 2016**
GoR A	**In cases of intimal dissection, vessel disruption, AV fistula, pseudoaneurysm or traumatic aortic rupture, the goal must be primary endovascular therapy.**	
2.119	**Recommendation**	**Modified 2016**
GoR 0	**In hemodynamically unstable patients in extremis, a temporary endovascular balloon occlusion can be carried out.**	
2.120	**Recommendation**	**2011**
GoR B	**If there is renewed bleeding after successful embolization, further treatment should also be interventional.**	

Explanation:

Requirements and Considerations for the Indications

Prior to interventional radiology to control a source of bleeding, a multi-slice CT (MSCT) examination with contrast should be performed to identify the source. In this case, endovascular therapy should be considered only if the MSCT shows evidence of active contrast leakage, because only then will there be adequate chances for visualization of the bleeding source as well as successful treatment within the intervention [26]. In addition, the bleeding must be in an area accessible to endovascular intervention.

It is also necessary that the patient can be sufficiently stabilized for the procedure with transfusion and intensive medical therapies. Sufficient personnel must be present including physicians experienced with the procedure as well as necessary material resources.

For the procedure to be indicated, other sources of bleeding accounting for the relevant blood loss (e.g., diffuse bleeding from multiple bony fractures) must be excluded.

The rules stated above apply to adult and adolescent patients. They are not directly transferable to children due to the anatomic considerations with smaller vessels that are still growing.

Materials and Techniques for Interventional Hemorrhage Control

There are diverse materials available to control bleeding within interventional radiology. These include non-coated and coated stents, balloon catheters, as well as solid and liquid embolization agents (e.g., metal coils, microspheres, or tissue adhesives).

The selection of the material to be used depends on the bleeding as well as the experience of the interventional radiologist, and requires a decision based on individual and situational conditions.

Stents are used particularly for vessel perforations and intimal injuries when blood flow of the vessel must/should be maintained, e.g. in the case of aortic dissection.

In contrast, embolization agents are used to seal vessels permanently (e.g. with metal coils) or at least temporarily (e.g. with resorbable gelatin particles). Since the effects of some embolization agents require intact clotting functions, these should be managed as much as possible prior to the intervention. As an alternative, non-clotting dependent embolization agents (all liquid embolization agents and PTFE-coated plugs) are used.

The appropriate selection of stent and particle sizes, etc., depends on the size of the target vessel; however, to avoid unintentional embolization of non-target vessels, particularly in the case of particle embolization, the presence of potential physiological or trauma-induced arteriovenous shunts should be considered. The goal of each embolization must be to perform the procedure in the most tissue-sparing manner possible. Care must be taken that there is residual perfusion of organs downstream and that downstream tissue damage is kept to a minimum.

Endovascular Therapy for Direct Injuries to the Medium and Large Vessels

In cases of direct injury to the medium and larger vessels with intimal dissection, vessel rupture, AV fistula formation, pseudoaneurysm formation, and traumatic rupture, primary endovascular therapy must be the goal. The value of endovascular therapy for traumatic aortic rupture in particular has been widely studied [2, 8, 9, 14, 16, 17, 21, 22, 28]. Almost all of these studies have reported benefits of endovascular therapy compared to open surgical procedures, which is why the endovascular method should be preferred in acute situations.

When selecting the appropriate therapeutic approach, not only must the technical feasibility and availability be considered, but also the necessary time window (unstable patients) as well as concomitant injuries (access routes, simultaneous operations).

Jonker et al. [14] reported significantly reduced in-hospital mortality (6 % for endovascular therapy vs. 17 % for open surgery; p = 0.024). Pulmonary complications, which are the most commonly occurring complications overall, occurred significantly less frequently in the group undergoing endovascular therapy (23.9% vs. 37.9%, p = 0.032). No significant differences were observed for the incidence of most other complications (cardiac complications, acute renal insufficiency, cerebral events, and paraplegia). Another advantage is the lack of potential early or late graft infections that can occur after open procedures.

However, it must be mentioned that there are other complications such as endoleaks or undesired distal embolizations that are method-dependent and occur only during endovascular intervention.

Embolization in Injuries to the Solid Organs of the Upper Abdomen or Pelvic Bleeds as well as Recurrent Hemorrhage

Depending on the severity of injury with bleeds of the liver, spleen, or kidneys, endovascular embolization can be performed as definitive treatment, as a supportive measure for operative bleeding control, or as bleeding control in cases of post-surgical bleeding after an open surgical procedure [6, 7, 10, 11, 13, 15, 24, 25]. Generally, selective to super-selective embolization is the goal. For example, embolization of the proximal splenic artery should be avoided in splenic bleeds, since there is increased risk for gastric wall ischemia or pancreatic infarction, and embolizations in this area might not sufficiently reduce perfusion pressure in the bleeding zone. In some cases, however, non-selective embolization can also be performed; for example, in cases of renal bleeding, when the injuries are so severe that a nephrectomy is planned once the patient's condition has stabilized.

Pelvic bleeding resulting in patient instability is relatively rare compared to the number of pelvic injuries, and thus, embolization is seldom necessary [1, 12, 20]. In the study of Hauschild et al., there was no reduction in overall mortality for patients undergoing embolization versus those without (17.6 % vs. 32.6 %, p = 0.27); however, there was a significant decrease mortality related to blood loss (0 % vs. 23.7 %, p = 0.024) [12]. In cases of pelvic bleeding where hemodynamics are affected and there is an indication for embolization, there is evidence that the embolization should be performed early. Agolini et al. found that early embolization reduced mortality (14 % mortality when performed within three hours vs. 75 % when performed later; $p < 0.05$) [1]. It should be kept in mind that often there is increased bleeding when operative hemostasis is attempted around the iliac vessels, since opening of the compartment can release the hematoma's tamponade effect and thus, increase venous bleeding [4, 23].

The current literature shows an increased frequency of embolization for injuries of the solid organs of the upper abdomen and for pelvic bleeding [24].

Temporary Endovascular Balloon Occlusion

For hemodynamically unstable patients in extremis, resuscitative endovascular balloon occlusion of the aorta (REBOA) or other large vessels can be used to restore central circulation and expand the time window to definitive surgery or interventional therapy. The technical principle and the procedure can vary. An overview of this is found in Stannard et al. [27].

Because this is a last resort approach for the most severe, life-threatening bleeding and/or during ongoing resuscitation efforts, the duration of occlusion should be determined on an individual basis. Accordingly, there is no defined time limit for the occlusion. This method is more commonly applied during military operations, because the specific injury patterns and the particular circumstances of care lead to severe blood loss situations that can be treated temporarily with balloon occlusion until definitive care [3, 19, 27]. There are also reports of use in the civil sector [3, 5]. Overall, however, the evidence is limited. In terms of method, the procedure is suitable for massive bleeding below the diaphragm (Zones II and III of the aorta) and is contraindicated for bleeding in the upper mediastinum [3, 18].

The evidence table for this chapter is found on page 239 of the guideline report.

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2.18 Imaging

Introduction

In addition to other important factors, rapid and reliable diagnostic imaging is a key component to the management of severely injured patients in the emergency department phase. It is of great importance for the treating team to recognize the patient's pattern of injury at an early stage in order to implement a priority-driven approach for the patient's continued management.

The introduction of spiral computed tomography to routine clinical practice in the early 1990s has revolutionized diagnostic radiology [39]. In 1998, the introduction of multi-slice CT technology (MSCT) enabled an eight-fold reduction of scanning times. This results from halving the rotation time while quadrupling the volume sampling with equal layer thickness, largely eliminating motion artifacts. Development of detector technology has also provided better resolution at decreased layer thickness for the calculation of three-dimensional and multiplanar reconstructions (MPR) [19, 42, 88].

Whole-body computer tomography (WBCT) has become both conceivable and technically feasible since the clinical introduction of multi-slice CT [19, 42]. This led logically to the consideration of how WBCT could be reasonably integrated as a diagnostic procedure within the early management phase of severely injured patients [49, 64, 65, 68]. It is highly recommended during the initial diagnostic assessment of polytrauma patients.

In 1997, Löw (from Mainz) was the first to report the use of whole body computed tomography within the context of severely injured patients [53]. This was followed by further reports from Scherer [74], Leidner [49], Ptak [65], Klöppel [43], and Rieger [68]. Since that time, there have been several approaches to integrate WBCT within emergency department trauma algorithms and/or protocols [8, 23, 40, 46, 64, 93, 95, 96].

An ever-increasing number of trauma centers are now routinely using WBCT for the assessment of polytrauma patients during ED trauma management [40, 95]. According to the 2014 annual report of the German Trauma Registry from the German Trauma Society (DGU), 71 % of all participating hospitals already use this type of assessment [91].

What is the actual evidence underlying diagnostic radiology? Following are the evidence-based key recommendations in the areas of ultrasound, conventional radiographs (C-spine, thorax, and pelvis), and computed tomography based on the systematic literature search described in the Methods section. It begins with key recommendations for diagnostic imaging of severely injured adults followed by a separate section with key recommendations for diagnostic imaging of severely injured children.

Imaging of Severely Injured Adults

Sonography/Ultrasound

Key recommendations:

2.121	**Recommendation**	**New 2016**
GoR B	**For diagnosis of free fluid after blunt or penetrating abdominal trauma, an eFAST* examination should be performed with the primary survey.** ***(eFAST: extended focused assessment with sonography in trauma; ultrasound examination of the abdomen, pericardium, and the pleura).**	
2.122	**Recommendation**	**New 2016**
GoR B	**Serial ultrasound examinations should be performed if CT chest cannot be performed in a timely manner.**	
2.123	**Recommendation**	**New 2016**
GoR B	**For the diagnosis of pneumothorax or hemothorax, transthoracic ultrasound should be performed as part of the eFAST examination.**	

Explanation:

Emergency ultrasound examination of the abdomen, pericardium, and the pleura is a routine screening examination for severely injured or potentially severely injured patients. In English-speaking areas, this is called the Focused Assessment with Sonography in Trauma (FAST). In the meantime, this examination has been expanded to include the thorax and the pleura, and is thus referred to as the extended Focused Assessment with Sonography in Trauma (eFAST). In German-speaking areas, it is used during trauma management for some 81 % of patients an average six minutes after admission to the emergency department [92]. Table 18 illustrates the regions examined on the eFAST [13].

There are a number of studies that all essentially show sufficient practicality and reliability of the examination technique.

Becker et al. evaluated the diagnostic reliability of FAST in 3181 patients divided into three groups according to the Injury Severity Score (ISS). The authors conclude that this is a reliable technique, but stress that the more seriously injured the patient is, the less sensitive the FAST. While the sensitivity is between 80-86 % for mildly injured patients with ISS ≤ 24, it is only 65 % for patients with ISS > 24. The specificity is high for all three groups with 97-99 % [7].

Comparable results were obtained by Ingemann et al. [38] (sensitivity 75%, specificity 96%), Lentz et al. [50] (sensitivity 87%, specificity 100%), Quinn et al. [66] (sensitivity 28-100%, specificity 94-100%), Richards et al. [67] (sensitivity 60-67%, specificity 98%), Schleder et al. [75] (sensitivity 75%, specificity 100%), and Smith et al. [79] (sensitivity 71%, specificity 100%).

All of the cited authors emphasize that a negative result by eFAST* does not in any way rule out the presence of intra-abdominal injury. The higher the overall injury severity, the less accurate the examination can be. In these cases, according to the cited authors, at least one repeat ultrasound or a supplementary CT examination should be carried out [7, 32, 35, 38, 41, 50, 66, 67, 75, 79, 85].

Table 18: Regions to be Examined with Ultrasound on the eFAST (extended Focused Assessment with Sonography in Trauma) according to Brun et al. [13]

Regions examined on ultrasound in eFAST
Hepatorenal Space (Morison)
Splenorenal Space (Koller)
Douglas Space (above the symphysis)
Pericardial Space (sub-xiphoid)
Right and Left Basal Pleural space
Right and Left Anterior-Superior Pleural space (midclavicular)

The following must be emphasized: Even if CT is available, routine assessment for free fluid with ultrasound of the abdomen, pericardium, and the pleura (eFAST)should be performed within the primary survey after blunt or penetrating abdominal trauma.

These days, since computed tomography and/or whole body computed tomography is commonly carried out during management of severely injured patients, it might lead some to consider the eFAST as superfluous and redundant. However, since the procedure can be performed very rapidly and without extra cost, and because a positive result will accelerate the course of treatment, it should be carried out even in cases when CT routinely follows. In the event of a technical failure of the CT or a mass casualty incident (MCI), it must be ensured that the eFAST technique is mastered across the treating team.

With regard to the third key recommendation (transthoracic ultrasound as a component of the eFAST), there is the following evidence:

In an analysis of 146 patients, Abassi et al. found that sensitivity for the detection of pneumothorax was 87 % with ultrasound versus 49 % with conventional radiographs. The specificity for both techniques was 100 %. The authors stress, however, that this technique must be learned. In the setting of their study, a two-hour training course was sufficient [2]. In a study of 142 patients, Abboud et al. found a relatively poor sensitivity for hemothorax by thoracic ultrasound, with only 12.5 % (specificity 98 %) [3]. Hyacinthe et al. found some better values in a study of 119 patients. The authors calculated a sensitivity of 53 % (pneumothorax) and 37 % (hemothorax) as well as a specificity of 95 % (pneumothorax) and 96 % (pneumothorax) for transthoracic ultrasound [37]. In an analysis of 79 patients, Nagersheth et al. yielded a sensitivity of 81 % and specificity of 100 % [61]. In a systematic review of four relevant studies [10, 81, 82, 97] (n = 606 patients) by Wilkersen et al., the authors calculated sensitivity values between 92 and 98 % and specificity values between 97 and 100 % for transthoracic ultrasound diagnosis of pneumothorax [94].

A feasibility study for a new technique to diagnose pneumothorax was published in 2013 by Lindner et al. Based on 24 patients, a sensitivity of 75 % and a specificity of 100 % were determined for a point-of-care radar technology, PneumoScan (micropower impulse radar, ultrashort electromagnetic signals). The authors of this study concluded that this technology needs further evaluation, but has potential for the pre-hospital and/or mass casualty settings [51].

Chest Xray

Key recommendation:

2.124	Recommendation	New 2016
GoR B	**In case it is unclear whether there is a relevant thoracic injury and chest CT is not immediately performed, chest xray should be performed.**	

Explanation:

Interestingly, there is little evidence regarding the diagnostic reliability of conventional chest xray (supine) in severely injured patients. In an analysis of 79 patients, Nagersheth et al. calculated sensitivity of 32 % and specificity of 100 % for the detection of pneumothorax by conventional chest (supine) radiographs [61].

In a systematic review of four relevant studies [10, 81, 82, 97] (n = 606 patients) by Wilkersen et al., the authors calculated sensitivity values between 28 and 76 % and specificity values of 100 % for the detection of pneumothorax on conventional supine chest radiographs [94].

They also pointed out the possibility to collect essential findings on the initial topogram of the computed tomography (here the thorax region). In this way, serious hemothorax and/or pneumothorax can be detected in emergency conditions.

Pelvis Xray

Key recommendation:

2.125	Recommendation	New 2016
GPP	**If it is unclear whether there is a relevant pelvic injury and CT is not performed immediately, pelvic xrays should be done.**	

Explanation:

There is no evidence known to us regarding the diagnostic reliability of conventional pelvis xrays in severely injured patients that fulfills the inclusion criteria of the S3 Guidelines. At the expert level, an analogous approach to that of the chest xray was approved by consensus.

They also pointed out the possibility to collect essential findings on the initial topogram of the computed tomography (here the pelvis region). In this way, displaced pelvic ring or acetabular fractures can be detected under emergency conditions.

Computed Tomography (CT)/Whole-Body Computed Tomography (WBCT)

Key recommendations:

2.126	**Recommendation**	**New 2016**
GoR A	**In the context of diagnostic studies for severely injured patients, whole-body CT* with a trauma-specific protocol must be performed in a timely manner.**	
	*** (Head to and including pelvis, CCT without contrast)**	
2.127	**Recommendation**	**New 2016**
GoR B	**Indications for whole-body CT in adults**	
	When the following criteria are met, whole-body CT should be carried out:	
	• Vital parameter disturbance (circulation, breathing, consciousness)	
	• Relevant mechanism of injury	
	• At least two relevant body regions injured	
2.128	**Recommendation**	**New 2016**
GoR B	**The CT scanner should be in or near the Emergency Department.**	
2.129	**Recommendation**	**New 2016**
GoR 0	**In hemodynamically unstable severely injured patients, immediate whole-body CT [1] with contrast can be performed under certain circumstances*.**	
	[1](head to and including pelvis, CCT without contrast medium)	
	***Prerequisites for this are a high degree of trauma team organization and the appropriate infrastructure.**	

Explanation:

Regarding the first key recommendation, there is the following evidence. In a 2009 multi-center analysis of 4621 patients of the DGU Trauma Registry, Huber-Wagner and Lefering et al. were the first to report a significantly positive effect on survival probability when whole body computed tomography (WBCT) was performed during the emergency department phase. The analysis was adjusted according to severity. Thus, for example, the expected mortality rate based on the RISC prognosis (Revised Injury Severity Classification Score) was 23 % versus the actual mortality of 20 % [47, 48]. This results in a number needed to treat (NNT), more accurately a number needed to scan, of at least 32. This means that every 32nd severely injured patient in whom WBCT is performed will survive contrary to the prognosis [34]. In another 2013 analysis of data from 16 719 DGU Trauma Registry patients, Huber-Wagner et al. confirmed that severely injured patients undergoing initial WBCT had an absolute mortality of 17.4 % compared to 21.4 % for patients not undergoing WBCT ($p < 0.001$) [32]. In an analysis of 4814 patients, Kanz et al. also identified a significant survival benefit for patients with WBCT [41]. In a 2012 study of 982 patients, Stengel et al. reported high sensitivity (85-92%), specificity (95-99%), a high positive predictive value (95-99%) and a high negative predictive value (86-97%) for WBCT in severely injured patients [85]. Thus, Stengel et al. provided proof of the high diagnostic reliability of WBCT. With these results, WBCT has the highest diagnostic accuracy and reliability of all other radiological procedures [85].

Regarding the second recommendation, there is the following evidence. In an analysis of 255 patients, Davies et al. developed a score system to aid decision-making. With a score > 3, WBCT is recommended; with scores $\leq$ 3, selective CT is advised. Injury of two or more injury regions yields +2 points, hemodynamic instability +2, respiratory insufficiency +3, Glasgow coma scale (GCS) $<$ 14 +3, fall $\leq$ 5 meters -1, motor vehicle accident victim within the vehicle +1, motor vehicle accident victim as bicyclist or pedestrian +3, fall $>$ 5 meters +3 [17]. The group of Hsiao considers multi-region injury as a particular indication for WBCT. The examination is based on a logistic regression model. Age over 65 years, male gender, GCS $<$ 14, hemodynamic instability, full trauma team activation, fall from more than 5-meter height, and accident victim as bicycle rider are signs of multi-region injuries [30]. Huber-Wagner et al. also developed a WBCT score to aid decision-making using an analysis of 78 180 patients of the DGU Trauma Registry. Propensity score analysis was systematically performed. A score of 0-3 points indicates moderate benefit of performing WBCT. A score of -16 to -1 indicates no survival benefit for WBCT, of 4-16 shows benefit, and a score of 17-35 shows high survival benefit of WBCT. Scores are assigned as follows: intubation at trauma scene (+8), suspicion of injuries to $\geq$ 3 body regions (+8), high energy trauma (+7), air rescue transport (+5), GCS $\leq$ 14 (+3), suspicion of injuries to 2 body regions (+3), shock at trauma scene (+2), male gender (+2), penetrating trauma (-7), low fall $<$ 3 m (-7), age $<$ 70 years (-1), suspicion of injury to one body region (-1) [33]. Ultimately, these three studies can be broken down in the three parameters disturbed vital signs, relevant mechanism of injury, and presence of more than one injury region, as meaningful indicators and/or predictors for the benefit of WBCT [17, 30, 33].

Regarding ideal location of the CT scanner with respect to the Emergency Department, there is the following evidence. Saltzherr et al. carried out a randomized study (REACT trial) of trauma patients in Holland assigned by lot either to a hospital performing initial conventional imaging with ultrasound and radiographs and supplemental CT evaluation in the radiology department if necessary, or to a hospital performing primary CT examination in the Emergency Department. Overall 1124 patients were evaluated, only 265 of them with multiple injuries. The entire collective was mildly injured with an average ISS of 6. Survival did not differ between the two groups; however, there was a significant time advantage for the CT-in-the-ED group. In the severely injured subgroup of 265 patients, there was a trend to survival benefit for the CT-in-the-ED group with 4.6 %, which was not significant because of the small case number [70]. Riepl et al. also reported a significant time advantage. Comparison of two collectives before and after installation of a CT scanner in the Emergency Department showed a gain of 22 minutes prior to CT examination and a gain of ten minutes in the overall ED phase for the CT-in-the-ED group [69]. With analysis of 8004 patients of the DGU Trauma Registry and the Trauma Network database, Huber-Wagner et al. reported that the location of the CT scanner significantly affected mortality for polytrauma patients. The closer the CT is located to or within the ED ($<$ 50m), the more beneficial the effect. Location $>$ 50 m distant from the trauma care area of the ED yielded significant adverse effects on outcome. The authors conclude that in cases where the Emergency Department is being built or renovated, the CT scanner should be placed as close as possible ($\leq$ 50 m) to the trauma care area [36]. They also refer to the possibility and positive experiences of the group around Gross et al., who are able to carry out diagnostic assessments in a "multifunctional image-guided therapy suite" [20].

Regarding the fourth key recommendation, there is the following evidence. With an analysis of 16 719 patients from the DGU Trauma Registry, Huber-Wagner et al. found that WBCT can be safely carried out also in hemodynamically unstable patients (patients in shock). The survival rate for patients in severe circulatory shock with blood pressure $<$ 90 mmHg on admission to the hospital undergoing WBCT was 42.1 % compared to 54.9 % without WBCT ($p < 0.001$). The authors remark that patients in shock might particularly benefit from WBCT, since the cause of shock can be detected especially quickly and comprehensively. It can be used to develop a rational management plan, for example for or against a particular emergency procedure. However, it should be explicitly pointed out that this type of diagnostic assessment should only be carried out on unstable patients in the presence of a well-organized trauma team and correspondingly good infrastructure with short travel distances [32].

Special Aspects for the Performance of Whole Body Computed Tomography

It has been pointed out that whole body CT with arterial contrast medium is particularly advisable for rapid detection of relevant bleeding. Unfortunately, however, there is no uniform protocol available for WBCT in severely injured patients. Also mentioned has been the possibility of performing WBCT with a dual-bolus administration of contrast medium. With this technique, rather than two separate visualizations of arterial and venous phases with two individual serial scans, one simultaneous (layered) representation of the arterial and venous phases is produced with a single scan [84, 89]. Also mentioned is the possibility to use the initial topogram of the CT like conventional chest and/or pelvis xrays.

It is unclear when CT-angiography of the neck vessels should be performed in trauma patients. Practically speaking, in cases of relevant trauma to the head/neck region, once the native cranial CT is completed, the neck region can be imaged with contrast so that relatively seldom but highly relevant injuries to the vessels in this region are not overlooked [16].

Radiation exposure is higher when the arms are positioned alongside the torso compared to when they are positioned over the head. The effect is about 3 mSv [50]. In practical terms, in hemodynamically stable patients, the arms can be positioned above the head if the injury pattern permits. In unstable patients, rapid diagnosis is of utmost priority; thus, the arms of these patients can be left alongside the torso to save time. Even positioning of a single arm overhead achieves a relevant exposure reduction [32, 52].

New generations of CT devices and the use of iterative protocols can markedly reduce radiation exposure from WBCT. A reduction of 30-80 % (!) is possible with this [21, 55, 62]. For this reason, the effective dose for WBCT under modern conditions should be less than 10 – 20 mSv [12], and even values of 5 – 10 mSv have been reported [21, 52, 55, 62]. In view of these values, the risk of radiation-induced long-term complications are reduced and is also outweighed by the attained positive survival effects [31].

Imaging for Severely Injured Children

Introduction

The most common cause of death in children is trauma. The proportion begins with 19.8 % in the age group 1 to 4 years and increases to 62.0 % between the 15th and 19th years of life [83].

The choice of suitable imaging in children is debated, since rapid and reliable diagnostic radiology is sought but on the other hand, the risk for malignancy from ionizing radiation is higher than in adults [56, 57, 63]. Generally, but especially when using CT, the ALARA principle (as low as reasonably possible) should be followed. Thus, Mueller et al. found that non-selective use of CT and use of non-adapted measurement protocols in children after blunt trauma led to effective whole-body exposure that correlates to increased risks for solid tumors and leukemias [59]. Schoeneberg et al. offer a current review of pediatric imaging within the trauma bay of the ED [77].

Berrington de Gonzalez et al. gave the probability for the development of a malignancy after whole body CT as 1:166 for a three-year-old girl and 1:333 for a boy of the same age. For a 15-year-old girl, the risk remains 1:250 and for boys, 1:500. For adults, the risk is 1:1500 [9].

Ultrasound (FAST) in Children

Key recommendations:

2.130	Recommendation	New 2016
GoR B	**For diagnosis of free fluid after blunt or penetrating abdominal trauma in children, an eFAST* examination should be performed with the primary survey.** *(eFAST: extended focused assessment with sonography in trauma, ultrasound examination of the abdomen, pericardium, and the pleura). **A negative result does not exclude an intra-abdominal injury. Close monitoring, and if needed, a detailed repeat examination or CT examination should be performed.**	

Explanation:

A 2007 meta-analysis by Holmes et al. included all publications through November 2005 on the subject of the “FAST” for identifying intra-abdominal injuries in children. Here they calculated a sensitivity of 50 % (95% CI: 41-59 %), a specificity of 97 % (95% CI: 95-98 %), a positive likelihood ratio of 14.8 (95% CI: 8.9-24.4), and a negative likelihood ratio of 0.51 (95% CI: 0.43-0.61) for FAST to detect evidence of intra-abdominal injuries in children [25]. In 2013, this meta-analysis was supplemented with studies up to and including June 2012. This meta-analysis included 1514 patients overall and yielded sensitivity of 56.5% (95% CI: 51.62 - 61.26 %), specificity of 94.68 % (95% CI: 93.4 -95.91%), positive likelihood ratio of 10.63 (95% CI: 8.16 - 13.84), and a negative likelihood ratio of 0.46 (95% CI: 0.41 - 0.51). Accuracy was 84.02 % (95% CI: 82.05 - 85.81 %) [78].

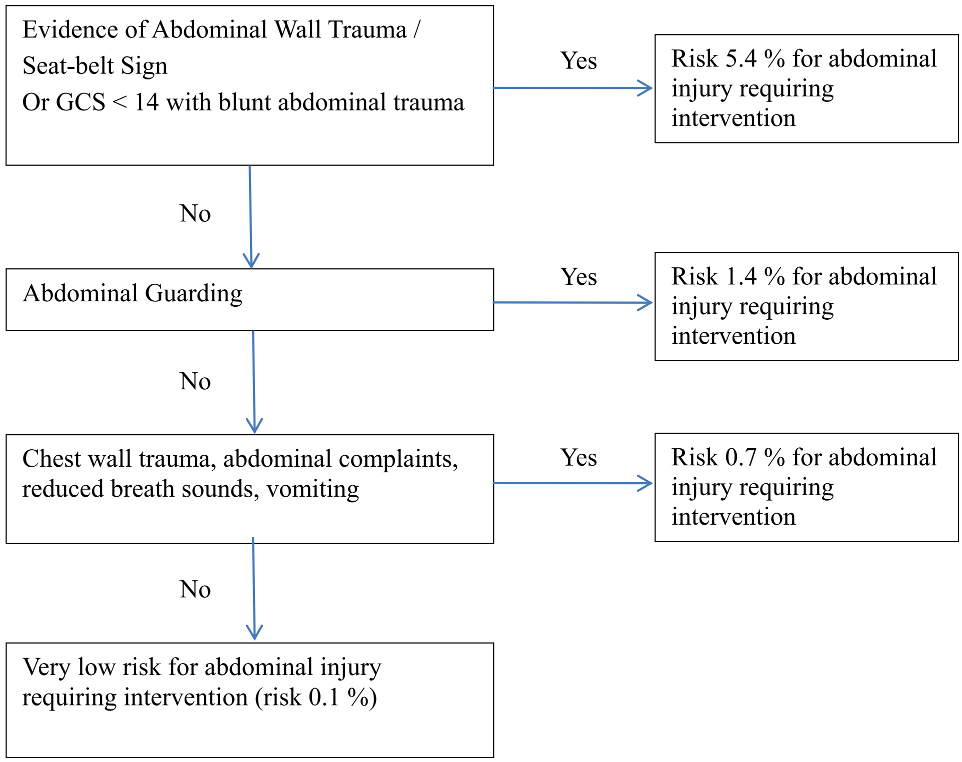
These two meta-analyses show that FAST alone has a low sensitivity for the detection of intra-abdominal injuries in children.

In the literature, elevated liver transaminases, pathological clinical examination findings, reduced systolic blood pressure, decreased hematocrit, and microhematuria have been reported as indicators for intra-abdominal injury [27, 29]. Sola et al. found that the combination of FAST with increased liver enzymes (AST or ALT $>$ 100 IU/L) increases the sensitivity from 50 % to 88 %, the specificity from 91 % to 98 %, the positive predictive value from 68 % to 94 %, and the negative predictive value from 83 % to 96 % for the detection of intra-abdominal injury in children [80]. In this study, the average ISS was 15.8.

However, most studies of FAST and other diagnostic alternatives for pediatric abdominal trauma were not performed in polytraumatized/severely injured patients, but in pediatric monotrauma with unclear injury severity. This is a fundamental constraint that limits the relevance of the interpretation for severely injured children.

The Pediatric Emergency Care Applied Research Network (PECARN) published a decision tree to identify children with very low risk of intra-abdominal injuries (Figure 1) [26]. This tree, developed in a prospective multi-center study of 12 044 pediatric patients, enables identification of children requiring immediate intervention with a sensitivity of 97 %. A prospective validation of this decision tree is still pending, so its use cannot be recommended without limitations.

Figure 8: PECARN Decision Tree to identify children with very low risk for abdominal trauma requiring intervention [26]



Pediatric Chest Xray

Key recommendation:

2.131	Recommendation	New 2016
GPP	**In case it is unclear whether there is a relevant thoracic injury and chest CT is not immediately performed, chest xray should be performed.**	

Explanation:
Severe chest trauma is the second leading cause of death in severely injured children [71]. The presence of severe chest trauma increases mortality in children 20-fold [90].

Thoracic ultrasound can be carried out as a supplement to chest xray. With this examination, pleural effusions, pneumothorax, lung contusions, and pericardial tamponade can be detected. The sensitivity to detect lung contusions in adults is higher than on chest xray [82].

To our knowledge, there is no high-quality evidence regarding the value of chest xray after severe pediatric trauma.

In a prospective study, Holmes et al. identified the following predictors for thoracic injuries in children: reduced systolic blood pressure, increased age-adjusted respiratory rate, pathological clinical chest examination, pathological auscultation findings, femur fracture, and GCS < 15. These findings should be followed up with further examinations of the chest [28].

- In a current review of pediatric chest trauma, the use of CT is recommended [58]:

- when positive pressure ventilation is required,
- in cases of penetrating trauma,
- in cases where tracheobronchial or vascular injury is suspected, when pneumothorax or hemothorax persists after chest tube placement, and
- in cases where aortic injury is suspected.

Pelvic Xray in Children

Key recommendation:

2.132	Recommendation	New 2016
GPP	**If it is unclear whether there is a relevant pelvic injury and CT is not performed immediately, pelvic xrays must be done.**	

Explanation:
For this point as well, there are no pediatric studies with high levels of evidence. With an incidence of approximately 4 % overall, pelvis fractures are relatively seldom in children [11]. Lagisetty et al. reported GCS < 14 and

tenderness to pelvic pressure as predictors of pelvic fracture. If there is no hematuria, abdominal pain, pelvic pressure tenderness, abrasions, hemorrhaging, or lacerations, pelvic fracture is unlikely [45].

The high elasticity of the pediatric pelvis should be considered. Because of this, some 20 % of complex pediatric pelvic injuries appear normal on conventional radiographs and CT. Thus, if pelvic injury is suspected clinically but is not detected on xray or CT, MRI might be necessary. When relevant pelvic bleeding is suspected, CT contrast should be performed.

Cervical Spine Xrays in Children

Key recommendation:

2.133	Recommendation	New 2016
GPP	**If it is unclear whether there is a relevant cervical spine injury and CT is not performed immediately, cervical spine radiographs should be done.**	

Explanation:

Cervical spine injuries are rare, with an incidence of about 1.4 %. However, when an injury occurs, it is associated with high morbidity and mortality [15].

Here overall there is a lack of studies with high level of evidence. A current review of diagnostic assessment of pediatric C-spine injuries [76] yielded the following remarks.

- C-spine injuries can be excluded without radiological assessment in children who are conscious and able to be clinically examined. For this, all NEXUS criteria and Canadian C-spine rule (CCR) conditions must be without pathological findings (Table 19). However, sufficient verbal and cognitive development must be present to use the NEXUS criteria and CCR. Thus, their use is not sufficiently reliable in children under 3 years of age [24, 54, 86, 87].
- When there is decreased level of consciousness or absent verbal communication, whether it is related to age, injury, or therapy, conventional C-spine xrays should be performed in two planes.
- Additional radiological views, such as flexion-extension images or a dens view, have almost no additional relevance. At most, a dens view can be taken as a supplement in children over 8 years of age.
- If conventional radiographs yield questionable findings, CT should be performed in cases of suspected fracture.
- MRI offers the most sensitive assessment for suspected soft-tissue injury. All children with neurological deficits should receive MRI evaluation during the course of management. In children who cannot be clinically evaluated because of longer-lasting reduced levels of consciousness (more than 72 hours), even when fracture was initially excluded with xray, MRI should be performed for definitive exclusion of injury.

Table 19: NEXUS Criteria and Canadian C-Spine Rule (CCR) [24, 54, 86, 87]

NEXUS Criteria	CCR
Spinous process tenderness	Dangerous mechanism of injury (Fall from a height > 1 m; motor vehicle accident with rollover or occupant ejection)
Intoxication	Spinous process tenderness
GCS < 15	Inability to rotate head 45° bilaterally
Focal neurological deficit	
Other painful injuries	

Cranial Computed Tomography (CCT) in Children

Key recommendation:

2.134	Recommendation	New 2016
GPP	**Cranial CT (without contrast) must be performed for a child with traumatic brain injury according to defined criteria.**	

Explanation:

According to the interdisciplinary S2K Guidelines Traumatic Brain Injury in Childhood [1], there are mandatory and optional indications for CCT examination. Mandatory indications are:

- Coma with signs of transtentorial herniation such as pupillary changes or decerebrate rigidity (for this, all ED trauma assessments after A, B, and C problem management should be aborted), persistent disorientation (GCS < 15)
- focal neurological deficits such as cranial nerve deficits, paresis, or seizures,
- Suspected impression fracture, basilar skull fracture, and open injuries.

Optional indications are:

- severe mechanism of trauma, e.g. MVA, fall from > 1.5 m (or > 0.9 m in children under 2 years) or unclear mechanism of trauma, strong or persistent headache,
- vomiting closely associated in time with the trauma force and occurring repeatedly,
- Intoxication with alcohol or drugs,
- Evidence of coagulopathy,
- pre-existing cerebral conditions.

When pediatric CCT is being performed, the current diagnostic reference values must be observed, and image reconstructions in the soft tissue and bony algorithms with reformations are mandatory [14, 22].

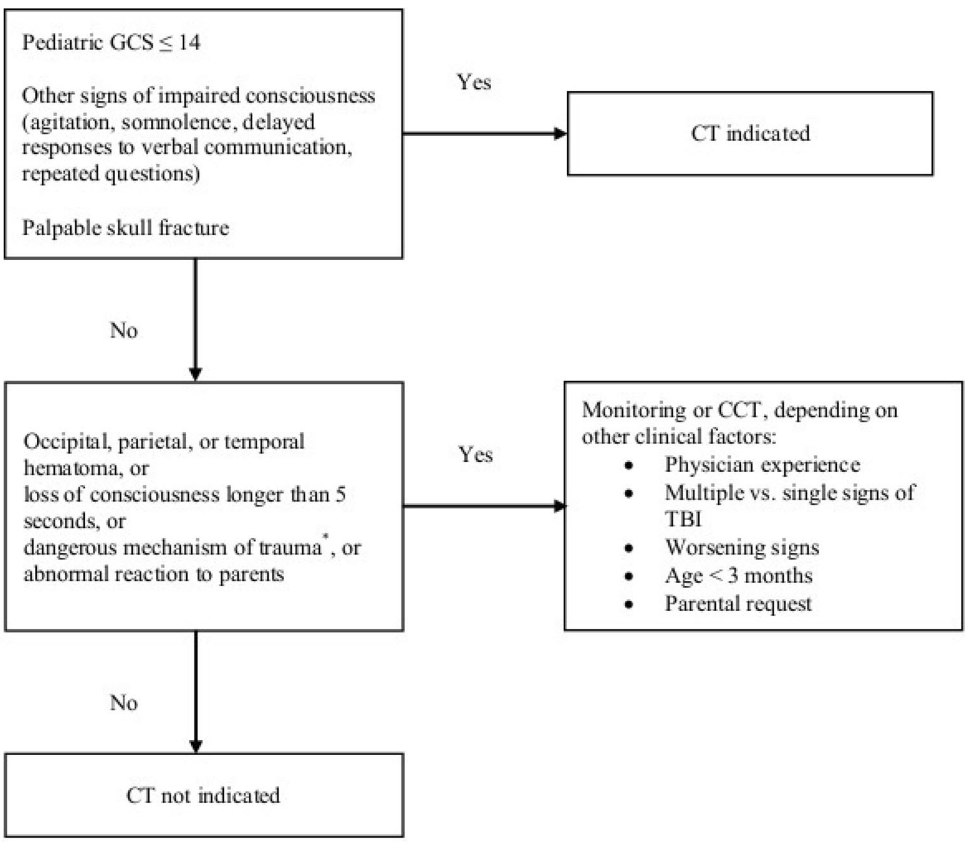
When optional indications are present, an alternative to CCT is close neurological monitoring for 24 hours [1]. The evidence of "CCT vs. in-patient monitoring" is ultimately unclear. In children aged up to around 18 months, trans-fontanel ultrasound can also be performed.

However, this does not exclude space-occupying bleeds near the calvarium under certain circumstances and the posterior fossa cannot be adequately assessed. Thus, a transcranial ultrasound should also be performed. In general, ultrasound of the skull is highly examiner-dependent. Thus, it cannot be unconditionally recommended.

In cases of optional indications for CCT and corresponding availability, magnetic resonance imaging (MRI) can be performed as an alternate procedure due to its higher sensitivity as well as specificity for parenchymal lesions [4]. This applies also when a child does not regain consciousness or over the course of treating unconscious patients. Cranial MRI protocols should include susceptibility-sensitive sequences and diffusion-weighted imaging (DWI), and (if applicable) FLAIR, T1, or T2-weighted sequences [5, 6, 73].

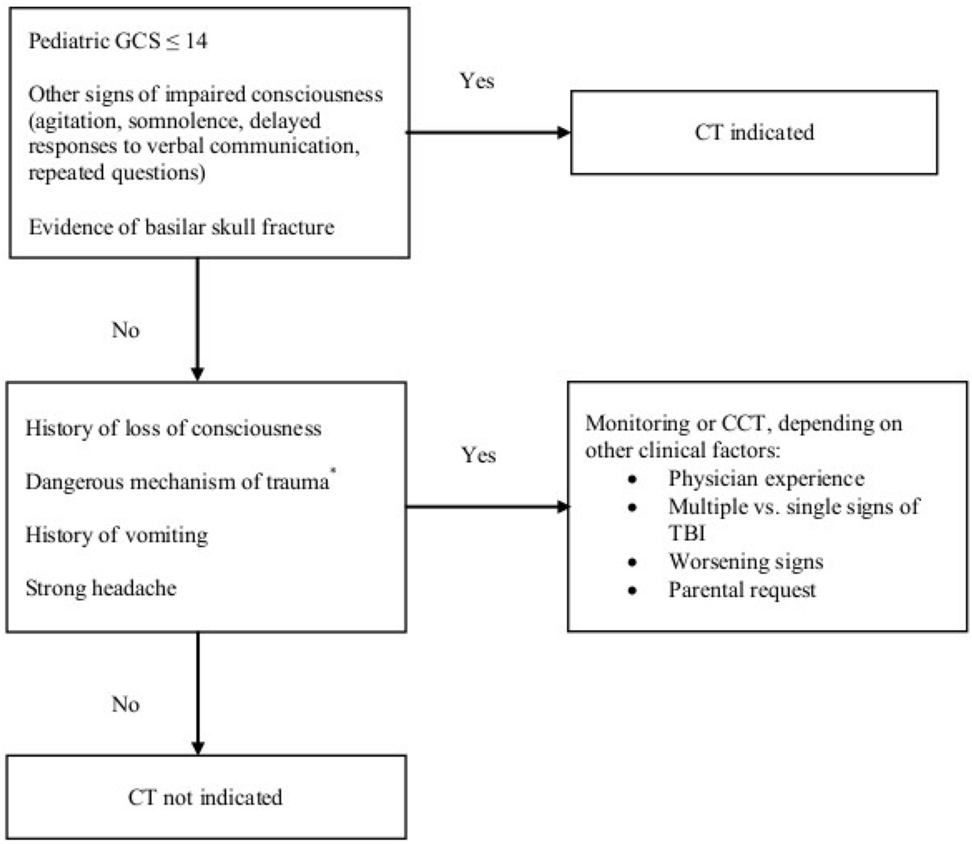
Together with the PECARN group, Kuppermann published an age-dependent CCT algorithm based on a prospective cohort analysis of 42 412 patients under the age of 18 (Figures 9 and 10) [44].

Figure 9: Diagnostic Recommendations for TBI in Children Younger than 2 Years



* MVA with ejected occupant, death of an occupant or rollover; pedestrian or cyclist without a helmet vs. car; fall > 0.9 m [44].

Figure 10: Diagnostic Recommendations for TBI in Children 2 Years and Older



* MVA with ejected occupant, death of an occupant or rollover; pedestrian or cyclist without a helmet vs. car; fall > 1.5 m [44]

Whole-Body Computed Tomography (WBCT) in Children

Key recommendation:

2.135	**Recommendation**	**New 2016**
GPP	**When treating severely injured children, whole-body CT* with a trauma-specific protocol** must be performed in a timely manner.** *** (Head to and including pelvis, CCT without contrast)** ****(as protection from excess radiation exposure, the diagnostic reference values for pediatric CT scans should not be exceeded. Monophasic intravenous contrast medium is suggested.)**	

Explanation:

In contrast to diagnostic assessment of severely injured adults [35], the evidence for reduced mortality with the use of WBCT is still pending. The ALARA principle must also apply here for the WBCT in severely injured children as with all investigations with ionizing radiation. However, it can be assumed that rapid assessment and reliable identification of all relevant injuries with WBCT will also optimize management in children and thus, reduce mortality. On the other hand, the non-negligible radiation exposure must be carefully watched, so that exposure is reduced as much as possible. Here, the current diagnostic reference values must be observed [14], and other pediatric-specific CT protocols should also be implemented. Thomas et al. published a protocol with coordinated dual contrast media administration, which prevents a duplicate scan of particular body regions [89]. Eichler et al. published a weight-adapted protocol that enables a complete trauma spiral with contrast administration and scan. In this study, using this protocol, no relevant injuries were missed [18]. According to Muhm et al., the mechanism of trauma alone should no longer be an indication for WBCT; instead, child age, level of consciousness, and clinical examination findings should be given higher importance. However, this must be evaluated with further studies [60]. Whole body magnetic resonance imaging might offer a radiation-free alternative to WBCT in the future. However, to this point the availability and the examination time, which is too long for an acutely severely injured child, remain obstacles [72, 77].

The evidence table for this chapter is found on page 243 of the guideline report.

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3 Primary Operative Management

3.1 Introduction

How would you decide?

A 35-year-old bicyclist has an accident. The patient is intubated and ventilated at the accident scene by the emergency physician. Volume replacement therapy is begun as hemodynamic support. The patient is brought to you for primary management. After exclusion of relevant intra-abdominal and intra-thoracic bleeding and after thorough assessment, the following injury pattern is evident: traumatic brain injury grade 2 (small subdural hemorrhage, contusion, etc.), chest trauma with multiple rib fractures and pronounced left pulmonary contusion, primary open left femoral shaft fracture, right distal tibia fracture. Initial laboratory tests show a hemoglobin value of 9.3 g/dl, INR of 0.77, and a base excess of -4.5 mmol/l. You consider your options for primary surgical management of this patient and weigh the pros and cons. The longer you consider, the more questions arise. What is the operative strategy of choice for the femur fracture? What is the optimal treatment for the distal tibia? Must the fibula be treated as well? Is it advisable to perform primary definitive treatment or is temporary fixation better? What roles do the traumatic brain injury and the thoracic injuries play in these decisions? You recall the management of similar cases in your department, the dogmatic repetitions of your "teacher" or other colleagues, the economic "restraints" placed by the hospital administration, and the perennial lack of time to adequately consider the almost limitless complex literature on the management of polytrauma patients. Ultimately, you decide once again to carry out a management strategy based on your own personal experience.

How would other German providers decide?

According to the database of the German Trauma Society's Trauma Registry, more than 65 % of all polytrauma patients have extremity and/or pelvic injuries (AIS > 2). This makes it even more astonishing that divergent operative strategies for femoral shaft fractures in a polytrauma setting are practiced and published [1]. According to analyses of the trauma registry, the primary treatment for femoral shaft fractures in multiply injured patients by some German hospitals is, almost dogmatically, always with external fixators. In other hospitals, it is almost always with intramedullary nails, and finally, in many hospitals, there is every conceivable combination, sometimes with fixators and sometimes with nails [1].

These differing approaches are based on two different operative strategies, which can ultimately be used on various body regions. The strategy of "Easy Total Care" promotes primary definitive management of injuries. Conversely, the "damage control" strategy for severely injured patients has the goal of avoiding secondary injury from surgery itself. For example, in the area of fracture care, primary definitive care is foregone, and instead, temporary stabilization is achieved with an external fixator. The smaller intervention and shorter operative time should keep the additional load, i.e. secondary damage, to a minimum.

The Goal of the "Primary Operative Management" Guideline Section

During the assessment of the overall condition of a trauma patient in the early post-trauma phase of care, there are a number of individual (e.g., age), trauma-specific (e.g., overall injury severity, pattern of injuries), and physiological (metabolism, coagulation, temperature, etc.) factors that must be taken into account. Although this can make the initial assessment more difficult, this assessment is the basis for the choice of operative approach during the primary operative management phase. It is generally accepted that patients in an overall stable condition benefit from definitive treatment and patients in less stable condition overall do better with "damage control." A recent analysis of the German Trauma Society's Trauma Registry shows that approximately 15 % of patients are assigned to an unclear overall condition ("borderline"). The optimal treatment strategy in the primary operative phase remains a controversial topic of debate particularly for these patients [1-12].

Thus, there is a continuing need for perspective regarding levels of evidence and grades of recommendation for various management strategies. The goal of this guideline section is to offer an overview of the evidence level of various treatment strategies during the primary operative phase after polytrauma and from this, to develop clinical treatment pathways (in cases of sufficient evidence) or document the need for further scientific review (recommendation grade).

Special Instructions:

In the context of this guideline section, assessment of the key issues is often complicated because "hard" scientific data is lacking, or because results are related to isolated injuries. This will be explicitly indicated in the corresponding areas, and the greatest effort will be made to offer the clearest possible individual recommendations for routine clinical practice despite the sometimes contradictory information in the literature.

When discussing fractures, it should be assumed –unless stated specifically otherwise – that the injury is closed, without vascular involvement and without compartment syndrome. Open fractures, vascular involvement, and compartment syndromes are considered indications for emergency surgery and may require different management strategies.

In addition, for certain fractures that require technically-challenging surgery (e.g., complex distal femoral or humeral condylar fractures), it is important for severely injured patients in particular that primary definitive treatment should only be considered if a) careful planning is made, if necessary based on 3D CT imaging, b) the expected operative time will not be too long, c) an experienced surgeon is present, and d) an appropriate implant is available in-house. For this reason, in many German trauma centers, such technically challenging fractures in polytrauma patients are initially stabilized temporarily, and definitive reconstruction is undertaken secondarily.

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3.2 Thorax

Operative Approach

Key recommendation:

3.1	**Recommendation**	**Modified 2016**
GoR 0	**Depending on the location of injury, anterolateral thoracotomy or sternotomy approaches can be used. When injury location is unclear, a clamshell approach can be selected.**	

Explanation:
The standard approach for emergency thoracotomy is anterolateral thoracotomy on the side of the injury at the level of the 4th-6th intercostal space. However, anterolateral thoracotomy seems to provide insufficient exposure to the injured organs in up to 20 % of cases [20].

If the exact location of the injury can be identified preoperatively, standard approaches can be used, e.g. posterolateral approach for procedures on the thoracic aorta or the intrathoracic trachea. A supraclavicular approach with mobilization or division of the clavicle enables safe visualization of the subclavian vessels in cases of injury there [4, 14, 44, 45].

Median sternotomy is preferred for injuries to the ascending aorta and the aortic arch as well as injuries of the great vessels and the heart [20, 43, 44]. Injuries to the posterior cardiac wall, however, are difficult to access through a sternotomy and are better reached through an anterolateral thoracotomy approach.

For trauma surgery, thoracoscopy is unsuitable for life-threatening emergencies. However, video-assisted thoracoscopy (VATS) can be performed for diagnostic and therapeutic purposes in patients with compensated cardiorespiratory function. For example, diaphragmatic injuries, lung parenchymal injuries, or sources of bleeding can be identified and treated. VATS is regularly used for hemothorax evacuation, usually after the acute management phase [14, 29, 44].

Penetrating Chest Injuries

Key recommendation:

3.2	**Recommendation**	**2016**
GoR B	**In the case of penetrating chest trauma, retained foreign bodies should only be removed under controlled conditions in the operating room after thoracotomy.**	

Explanation:
Once it is clear that there has been perforation of the chest wall, a foreign body penetrating the thorax must not be removed due to the possible tamponade effects or secondary injuries caused by improper removal. Removal takes place in the operating room or in the trauma care area of the ED during exploratory thoracotomy. In certain cases of hemodynamically stable patients, VATS can be considered for foreign body removal. Airtight closure or binding of puncture wounds is contraindicated, because they enable decompression of the pleural cavity. If decompression is not achieved with chest tube placement, the chest wound should be treated with a sterile, semi-occlusive dressing.

Indication for Thoracotomy

Key recommendations:

3.3	**Recommendation**	**2016**
GoR A	**A penetrating chest injury that is the cause of hemodynamic instability must undergo immediate exploratory thoracotomy.**	
3.4	**Recommendation**	**2016**
GoR 0	**Thoracotomy can be performed for cases with initial blood loss > 1500 mL from the chest tube or with continuing blood loss > 250 mL/hour for more than four hours.**	

Explanation:
In penetrating trauma, indications for immediate thoracotomy include severe hemodynamic shock, signs of pericardial tamponade, profuse bleeding, absence of peripheral pulses, and cardiac arrest when vital signs were initially observed and/or arrest began no longer than five minutes previous [14, 20, 44]. After chest tube placement, hemodynamically stable patients can be monitored and/or undergo further diagnostic assessments like spiral CT with contrast. Studies of predominantly penetrating injuries during the Vietnam War found that mortality and complication rates were reduced when thoracotomy was performed for initial blood loss $>$ 1500 ml or more than 500 ml in the first hour after chest tube placement [28].
A multi-center study also reported an association between mortality and thoracic blood loss regardless of mechanism of injury (blunt versus penetrating). Mortality rose by a factor of 3.2 in the group with chest tube blood loss of more than 1500 ml versus 500 ml in the first 24 hours. Thoracotomy was performed an average 2.4 $\pm$ 5.4 hours after admission [19]. Other authors [9, 19, 25, 28, 43] follow the concept to perform thoracotomy in blunt or penetrating trauma for an initial blood loss of 1500 ml or continuous bleeding of 250 ml/h over 4 hours. If the quantity of drainage per time unit is used as an indication for thoracotomy, the chest tube(s) must be correctly placed and draining reliably [44].

In case of combination chest injuries with great blood loss and pronounced metabolic derangement, temporary chest closure consistent with a damage control strategy can be performed once acute management and bleeding control has been completed. Once the vital parameters have been stabilized and there is restoration of coagulation and end-organ function, definitive surgical management and closure of the chest can be performed [9, 15, 17, 43].

Lung Injuries

Key recommendation:

3.5	Recommendation	2016
GoR B	**If surgery is indicated because of lung injuries (persistent bleeding and/or air leakage), the intervention should be parenchyma-sparing.**	

Explanation:

Parenchymal injuries of the lung after penetrating or blunt chest trauma with persistent bleeding and/or air leakage require surgical treatment [13]. One of the main indications for exploratory thoracotomy is profuse or persistent bleeding (1500 ml initially or 250 ml/h over 2-4 hours) [19]. In this case, corresponding operative management for potential lung parenchymal injuries might be indicated for bleeding control. Compared to parenchyma-sparing procedures – such as primary closure, pulmonary tractotomy, atypical resection or segment resection – lobectomy and pneumonectomy are associated with higher complication and mortality rates [9, 15, 17, 43]. At the same time, blunt trauma injuries seem to be associated with worse prognosis in terms of hospital duration, complications, and mortality [27].

Injuries of the Great Vessels

Key recommendations:

3.6	Recommendation	2016
GoR B	**In cases of thoracic aortic rupture, if technically and anatomically feasible, endovascular stent prosthesis is preferable to open revascularization procedures.**	
3.7	**Recommendation**	**2016**
GoR B	**Until aortic reconstruction, or in cases of conservative management, systolic blood pressure should be kept 90-120 mmHg.**	

Explanation:

Traditional treatment for aortic rupture consists of aortic reconstruction through direct suture with aortic clamping and using various bypass procedures to perfuse the lower half of the body and the spinal cord during clamping (left heart bypass, Gott shunt, heart lung machine) [6, 31].

Current studies have identified acute stenting for aortic ruptures as a minimally invasive, time-sparing therapeutic option with minimal injury from the approach [33]. Complications like reduced cerebral or spinal perfusion with the associated consequences, such as paraplegia, occur less frequently. Long term anticoagulant therapy, which is necessary for most bypass procedures, can be avoided [41]. In a current meta-analysis comparing open aortic reconstruction with endovascular stenting, the same technical success rate yielded significantly lower mortality as well as a significantly lower rate of postoperative neurological deficits (paraplegia, stroke) for stenting [34]. However, to date there is no long-term survival data after endovascular aortic reconstruction [37]. Overall, according to the current literature, endovascular stent prosthesis appears preferable to the conventional procedure [12].

Complications such as paraplegia and acute renal failure generally occur during open procedures due to operative-dependent ischemia. Complication rates correlate with clamping time of the aorta [18].

If perfusion is maintained during surgery with bypass procedures, complication rates (paraplegia, renal failure) decrease [5, 6, 13, 31].

The hemodynamic status of the patient at the time of admission determines the timing of aortic rupture management. Patients who are hemodynamically unstable or in extremis must undergo immediate surgery [5]. For patients with concomitant traumatic brain injury, severe abdominal or skeletal injuries requiring immediate operative intervention, and in older patients with pronounced cardiac and pulmonary comorbidities, aortic injuries can be treated with delayed urgency after additional life-threatening injuries and/or overall condition have been treated and stabilized [43, 44]. In a series of 395 patients, Camp et al. found that the mortality for hemodynamically stable patients undergoing non-emergent (> 4 hours) or delayed surgery (> 24 hours) was not higher than in those undergoing emergent surgery (< 4 hours) [10]. This opinion is shared by other authors [12, 13]. Delays to surgery of up to seven months may be tolerated in certain cases [35].

If surgery is not carried out emergently, strict pharmacological control of blood pressure (SBP between 90 and 120 mmHg and heart rate < 100/min) is necessary with beta blockers and vasodilators [12, 13].

Treatment of aortic dissection follows the same principles, with the difference that operative management always occurs during a secondary phase since it is not acutely life threatening.

Cardiac Injury

Life-threatening cardiac injuries occur predominantly through penetrating trauma. Injuries to multiple chambers are particularly associated with high mortality [14, 44]. Intra-pericardial injury of the inferior vena cava often causes life-threatening pericardial tamponade that needs immediate decompression. Operative treatment of the vena cava follows pericardial decompression, through the right atrium with direct suture or patch closure under extracorporeal circulation [42-45].

The approach is made with highest urgency through a left anterolateral thoracotomy or a median sternotomy. After decompression of the pericardial tamponade, which occurs in more than 50 % of cases, rapid control of bleeding is performed with suture or stapler through a longitudinal incision of the pericardium. After clamping of the bleeding atrial wall (Satinsky clamp), direct suture can follow here [30]. In difficult situations, a Foley catheter can be used as a temporary solution with intraventricular blocking. Ventricular lesions are closed with a pericardial patch or with Teflon felt augmentation. If possible, care should be taken of the coronary arteries while sewing to avoid a secondary infarction. Finally, the pericardium is left open or there is a loose approximation of the pericardial incision to avoid recurrent tamponade [14, 44]. There is no need for immediate thoracotomy for injuries not affecting hemodynamics, isolated septum defects, valvular injuries, or ventricular aneurysms [30]. These cases generally become evident after emergency stabilization of the patient because of persistent instability. Transesophageal echocardiography confirms their presence.

Proximal lesions of the coronary vessels must be reconstructed or treated emergently with aorto-coronary bypass, generally using a heart-lung machine [8]. Distal coronary lesions can be sutured or ligated [14, 44].

The initial cardiac rhythm and cardiorespiratory function of the patient at the time of ED arrival have prognostic relevance [1, 2]. Thus, attempts to maintain cardiac pump function and treat arrhythmias must be made, as this decreases mortality [1, 2]

Injuries of the Tracheo-Bronchial System

Key recommendations:

3.8	**Recommendation**	**Modified 2016**
GoR B	**If there is clinical suspicion of injury to the tracheobronchial system, diagnostic tracheobronchoscopy should be performed to confirm the diagnosis.**	
3.9	**Recommendation**	**2016**
GoR B	**Traumatic injuries of the tracheobronchial system should be surgically treated as soon as possible after diagnosis.**	
3.10	**Recommendation**	**2016**
GoR 0	**For localized injuries of the tracheobronchial system, conservative management can be attempted.**	

Explanation:

Injuries to the tracheo-bronchial system are rare and often a delayed diagnosis [3, 21, 36]. Tracheo-bronchial injury can also occur occasionally as a complication of orotracheal intubation [38]. Penetrating injuries predominantly affect the cervical trachea, while blunt trauma generally results in intrathoracic injuries. The right main bronchus near the carina is more frequently affected [3, 21, 36]. If there is persistent pneumothorax despite correct positioning and function of the chest tube, subcutaneous emphysema, or atelectasis, suspected tracheo-bronchial injury should be evaluated with tracheobronchoscopy [3, 21, 36]. Tracheal ruptures occurring at the level of the endotracheal tube cuff are initially covered and often missed because of positioning. Thus, during endoscopy, the endotracheal tube should be withdrawn to examine for tracheal ruptures.

Fiberoptic intubation with cuff placement distal to the defect can be performed immediately to secure the airway. In a retrospective study, Kummer et al. determined that a large number of patients required a definitive airway (tracheostomy) [22]. The emphasis here was on penetrating injuries. Operative treatment of the tracheo-bronchial system should be performed as soon as possible after diagnosis, because delayed treatment is associated with higher complication rates [30]. Surgical management of airway injuries yields a significantly lower mortality than conservative therapy [3, 21, 36]. Once bronchoscopy has been completed, conservative therapy should be considered only in patients with small bronchial tissue defects (defect smaller than 1/3 of the bronchus circumference) and well adapted bronchial margins [3, 11, 21 36]. A retrospective study by Schneider and colleagues identified no difference between conservative and operative management for cases of iatrogenic tracheal injuries without ventilation disturbance and superficial or covered tracheal tears [38].

Injuries to the cervical trachea were treated through a collar incision. For injuries to the intrathoracic trachea and the main bronchus, a right posterolateral thoracotomy approach should be used in the 3rd-4th intercostal space [30]. For simple transverse tears, end-to-end anastomosis of the bronchus should be performed after bronchus mobilization and cartilage removal when necessary. If direct suture is not possible in longitudinal tears with defects of the parietal membrane, they can be closed with a patch to avoid bronchial stenosis [3, 21, 36]. According to the current literature, stent-assisted treatment of tracheobronchial injuries appears irrelevant.

Injuries of the Bony Thorax (excluding Spine)

Explanation:

Bony injuries of the chest wall include fractures of the sternum, the ribs, and combinations thereof. Nearly half of all severely injured patients have rib fractures. Of these, two thirds have fractures without relevant chest wall instability and one third have an unstable thorax (flail chest), of whom again nearly one third have bilateral involvement. Sternum fractures without concomitant rib fractures are infrequent, found in fewer than 4 % of all severely injured patients. In combination with rib fractures, sternum fractures are present in approximately 7 to 21 % of severely injured patients [39].

The majority of uncomplicated fractures can be treated conservatively. Consistent pulmonary hygiene and adequate pain therapy are crucial. For many fracture patterns, including flail chest, a prolonged need for artificial respiration with positive pressure ventilation creates an "internal pneumatic splint," yielding a favorable position for consolidation [10]. This can be the case, e.g. in severe lung contusion or severe traumatic brain injury [43].

However, if the unstable chest wall itself is the main reason that ventilation is required, operative stabilization can shorten the duration of ventilation as well intensive care unit stay. A number of recent studies confirm this [7, 23, 24, 26, 40].

In addition, the following indications for operative treatment are found in the literature:

Sternum fractures [16]

- Strong, persistent, or intractable pain
- Respiratory insufficiency or ventilator-dependence
- Overlapping or impressed fractures
- Sternum deformity or instability
- Non-union/pseudarthrosis
- Deformed posture due to rib deformity and/or pain
- Limited range of motion

Rib fractures [32]

- Unstable chest wall (flail chest) with weaning failure or paradoxical chest excursions on weaning
- Prolonged pain
- Chest wall deformity
- Symptomatic non-union/pseudarthrosis
- Thoracotomy for another indication (rib fixation during "closure" of the thorax)

Various implants are available for chest wall stabilization like metal brackets, rib clamping systems, and various plates. Wire and suture are not unimportant. Stabilization of the bony chest wall is considered for and performed on stable patients; generally for severely injured patients, it is not part of primary operative management.

The evidence table for this chapter is found on page 277 of the guideline report.

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3.3 Diaphragm

Key recommendation:

3.11	Recommendation	2011
GoR B	**Once recognized during the initial diagnostic survey and/or intraoperatively, traumatic diaphragm rupture should be rapidly closed.**	

Explanation:

Diaphragm rupture is present in 1.6 % of blunt trauma patients and mostly occurs during motor vehicle accidents with side impact. It predominantly affects the left side [1, 3-6, 9, 11].

There is no valid data regarding the ideal time frame for surgery in patients with multiple injuries. It seems clear that in cases where abdominal organs have moved into the thorax, closure of the rupture should be performed rapidly. This also applies for cases in which the rupture is detected incidentally during surgery where the space has been opened for another injury.

However, there is no current clear evidence that delayed closure increases mortality. A random effects meta-regression of 22 studies (n = 980) from the years 1976-1992 [11] found that the overall mortality of 17 % showed no association between the incidence of delayed treatment and mortality (beta 0.013, 95% CI: -0.267 to -0.240). In a current analysis of 4153 patients from the National Trauma Database, pleural empyema was also not correlated with the timing of operative interventions [2].

In an acute situation with a hemodynamically unstable patient without thoracic injury, the ideal surgical approach is transabdominal. In cases of verified combination injuries, poor visualization, or technically difficult suture, a thoraco-abdominal approach is used [2, 8, 11].

The diaphragmatic defect can usually be closed with direct suture, and rarely is plastic defect coverage necessary [1, 8, 9]. The data available offers no conclusions regarding success rates of certain suture techniques (continuous versus interrupted) or material (monofil versus braided, resorbable versus non-resorbable). Endoscopic techniques are suitable for closing post-traumatic diaphragmatic hernias [7, 10]; in the primary operative phase of a polytrauma patient, the selection of laparoscopic or thoracoscopic approach must be critically evaluated.

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3.4 Abdomen

Surgical Approach

Key recommendation:

3.12	Recommendation	2016
GoR B	For trauma cases, midline laparotomy should be used over other approaches.	

Explanation:

Midline laparotomy is an anatomically based, universal surgical approach to the injured abdomen. It provides good visibility of all four quadrants, and can be performed more quickly and with less bleeding than transverse incisions, especially in trauma situations.

There is only one quasi-randomized study (assigned to treatment groups according to even or odd admission number), now over thirty years old, in which the midline laparotomy was compared to an upper abdominal transverse laparotomy in trauma patients [68]. The wound infection rates for patients with negative and positive findings on laparotomy were 2 % and 11 %, respectively, regardless of approach. In positive laparotomy, the average duration of anesthesia was 25 minutes shorter in patients having undergone a midline versus transverse approach (Table 20). According to the published data, this difference was statistically significant (p = 0.02). However, no standard deviations were reported and operative times were not further analyzed. This study cannot serve as evidence for selecting one approach over the other, but supports the idea of surgeon preference ("Adequacy of organ exposure is still a matter of personal preference").

Indirect evidence comes from randomized studies for elective abdominal procedures. A Cochrane review presents advantages of the transverse approach regarding postoperative need for morphine equivalents, lung function, and rates of incisional hernias [11]. There was no difference in the rates of pulmonary complications or wound infections. The multi-center randomized POVATI (Post-surgical pain Outcome of Vertical and Transverse abdominal Incisions) study of 2009 reported equivalent primary endpoint postoperative analgesia requirements and no difference in the secondary endpoints such as pulmonary complications, mortality, and incisional hernias at one year [62].Here, the authors also stress the possibility of a situation-dependent approach to the abdomen ("The decision about the incision should be driven by surgeon preference with respect to the patient's disease and anatomy").

There are still no clinical studies available to enable comparison of emergency laparoscopy and emergency laparotomy in multiply injured patients. One should continue to follow the consensus of the EAES that the current collection of evidence does not enable a clear recommendation in favor of therapeutic laparoscopic procedures for polytrauma patients with severe abdominal trauma ("Nevertheless, the scarceness of clinical data prohibits a clear recommendation in favor of therapeutic laparoscopy for trauma") [37, 61].

Table 20: Midline vs. Upper Abdominal Transverse Laparotomy in Abdominal Trauma

Study	LoE	Patients	Results	
Stone et al. 1983 [68]	2b	339 patients with blunt or penetrating abdominal trauma	Midline Laparotomy (n = 177)	Upper Abdominal Transverse Laparotomy (n = 162)
			Mean duration of anesthesia: positive laparotomy (n = 66) 215 min, negative laparotomy (n = 111) 126 min	Mean duration of anesthesia: positive laparotomy (n = 61) 240 min, negative laparotomy (n = 101) 132 min

Damage Control (DC): General Principles

Key recommendation:

3.13	Recommendation	Modified 2016
GoR B	In hemodynamically unstable patients with complex intra-abdominal damage, the damage control principle (hemostasis, packing, temporary abdominal closure/laparostoma) should be used over definitive reconstruction.	

Explanation:

The term “damage control” (DC) was coined by the US Navy and originally referred to a vessel’s ability to remain operational despite damages taken [17]. The basis of and indication for a DC or an abbreviated/truncated laparotomy is the AHC “trauma triad of death” consisting of acidosis (pH < 7.2), hypothermia (Temp < 34 °C), and coagulopathy (INR > 1.6 and/or transfusion need > 4l in OR) [59].

There is no currently standardized or uniform DC algorithm; however, there certain elements that are generally accepted as essential [29, 44, 46, 59].

1. Rapid hemostasis and prevention of any (further) peritoneal contamination
2. Temporary abdominal closure
3. Intensive care stabilization of core temperature, hemodynamics, and coagulation
4. Planned re-operation for the repair and reconstruction of organ injuries
5. Definitive abdominal wall closure

In the primary operative management phase of care, hemostasis (“stop the bleeding”) as well as contamination control (“stop the contamination”) are the key maneuvers. An important element in the case of bleeding from the liver is peri-hepatic packing. Here, the liver should be fully mobilized from the suspensory ligaments and packing applied around the posterior para-caval surface and sub-hepatic between the liver and the hepatic flexure of the colon to achieve compression against the diaphragm and the retroperitoneum, without compromising venous return from the hepatic veins [7, 25, 26, 43, 57].

A survival advantage was documented in three small retrospective cohort studies for patients undergoing DC compared to primary definitive surgical management (definitive laparotomy, DL) [47, 58, 69]. In contrast, another retrospective cohort study found a survival advantage for the DL group [52] (Table 21). The pooled relative risk (random effects) was 0.79 (95% CI: 0.48-1.33) in favor of DC. When only the maximal injury group of the Rotondo [58] study is considered, the pooled relative risk is 0.60 (95% CI: 0.30–1.19). None of these studies performed multivariate adjustment for differences in injury severity or other confounders; thus, the results are subject to bias.

Despite an extensive search strategy in nine databases (including congress abstracts and “gray” references) as well as a hand search, authors of a Cochrane review were unable to identify any randomized studies [15].

Individual reports suggest survival rates of 90 % after DC even when there is an unfavorable prognosis based on the initial presentation [40]. In most larger case series, however, mortality for patients requiring DC laparotomy is between 25 and 50 % [3, 5, 63].

The Pringle maneuver, with clamping of the portal vein and the common hepatic artery, might be the oldest DC technique for temporary hemostasis in cases of severe hepatic injury [56]. Although an ischemia time of 45-60 minutes is tolerated without severe post-operative functional deficits of the liver parenchyma by patients without pre-operative shock, full expenditure of this ischemia time markedly increases the risk of post-operative liver failure in multiply injured patients [43]. In a Chinese case series, 5 of 7 patients died after the Pringle maneuver was used for a retrohepatic caval tear [27].

Table 21: Damage Control vs. Definitive Treatment

Study	LoE	Patients	Results	
Stone et al. 1983 [69]	2b	31 patients with penetrating or blunt abdominal injuries and intraoperative development of coagulopathy	Definitive Treatment (n = 14)	Damage Control (n = 17)a
			Overall survival rate: 1/14 (7 %)	Overall survival rate: 11/17 (65 %)
			RR 0.11 (95% confidence interval: 0.02-0.75)	
Rotondo et al. 1993 [58]	2b	46 patients with penetrating abdominal injuries	Definitive Treatment (n = 22)	Damage Control (n = 24)b
			Overall survival rate: (55%)	Overall survival rate: 12/22
				14/24 (58 %)
			RR 0.94 (95% confidence interval: 0.56-1.56)	
			Survival rate for max. injury: 1/9 (11 %)c	Survival rate for max. injury: 10/13 (77 %)c
			RR 0.14 (95% confidence interval: 0.02-0.94)	
MacKenzie et al. 2007 [47]	2b	37 patients with penetrating or blunt liver injury grade IV/V	Definitive Treatment (n = 30)	Damage Control (n=7)
			Overall survival rate: (63%)	Overall survival rate: 19/30 7/7 (100 %)
			RR 0.63 (95% confidence interval: 0.48-0.83)	

Study	LoE	Patients	Results	
Nicholas et al. 2003 [52]	2b	250 patients with penetrating abdominal injuries	Definitive Treatment (n = 205)	Damage Control (n = 45)
			Overall survival rate: 184/205 (90 %)	Overall survival rate: 33/45 (73 %)
			RR 1.22 (95% confidence interval: 1.02-1.47, p = 0.0032)	

a: Immediate arrest, packing, abdominal closure under tension; mean duration to second look: 27h
b: Four quadrant packing, hemostasis, ligature or simple (clamp) suture for hollow organ injuries, temporary abdominal wall closure; mean duration to second look: 32h
c: Injury to the great vessels + $\geq$ 2 organs injured; packing + angioembolization

Damage Control: Temporary Abdominal Wall Closure

Key recommendation:

3.14	Recommendation	Modified 2016
GoR B	**After DC laparotomy, the abdomen should be closed temporarily and without fascial suture.**	

Explanation:
Primary fascial closure after DC laparotomy increases the risk for abdominal compartment syndrome (ACS). Compared to skin closure alone or the placement of a 3-liter cystoscopy (Bogota) bag, the use of primary fascial suture increased the relative risk for ACS 6-fold [54]. The reduced risk for ACS with temporary closure is accompanied by fluid loss and impaired temperature regulation through the large exchange surface as well as difficulty with fascial closure during abdominal wall reconstruction.
There has been wide application worldwide of vacuum-sealing [8,10], Bogota bag equivalents, or commercial products with zip or Velcro closures (Wittmann patch or Artificial Burr) as temporary materials [2].
The common principle of all established laparostoma systems is mechanical protection of the organs through insertion of a plastic film.

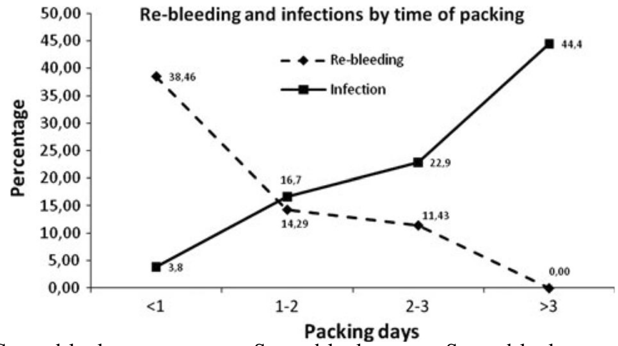
Damage Control: Second Look after Packing

Key recommendation:

3.15	Recommendation	Modified 2016
GoR B	**After packing intra-abdominal bleeding, the second-look operation should follow between 24 and 72 hours after the initial intervention.**	

Explanation:
A "second look" operation is necessary within the damage control sequence for further treatment of organ injuries after packing of the intra-abdominal bleeding and subsequent intensive care stabilization.
This surgical intervention can be definitive surgical care or simply exchange of the used packing material and further contamination control. Here, a balance must be maintained between the risk of renewed bleeding and that of possible complications (infection, fistula formation, restricted pulmonary function, abdominal compartment syndrome).
The available data from retrospective cohort studies shows that unpacking after 24-36 hours is associated with increased risk of bleeding (pooled relative risk, fixed effects: 3.51, 95% CI: 1.39-8.90) [13, 53]. There is no clear evidence that the risk of septic complications is increased when abdominal dressings are left for 48 hours (pooled relative risk, fixed effects: 1.01, 95% CI: 0.59-1.70) [1, 13, 19, 53]. However, the study by Abikhaled found that when packing materials were left in place for longer than 72 hours there was an associated 7-fold increase in the relative risk for intra-abdominal abscesses (6.77; 95% CI: 0.84–54.25) [1]. These results were confirmed in a current study by Ordonez on 121 patients undergoing DC laparotomy with abdominal packing after penetrating abdominal trauma. When removing abdominal packing within 24 hours, bleeding complications dominate, and after 72 hours, infections are in the foreground [55].
Thus, the second look operation should not occur earlier than 24 hours and not later than 72 hours after the initial surgery.

Table 22: Second Look after Packing

Study	LoE	Patients	Results		
Ordonez et al. 2012 [55]	2b	121 patients with penetrating abdominal trauma Second look < 24 h (n = 26) 24-48 h (n = 42) 48-72 h (n = 35) > 72 h (n=18)			
Nicol et al. 2007 [53]	2b	93 patients with penetrating or blunt liver trauma	Second look 24 h: (n = 25): Re-Bleeding: 8/25 (32 %) Packing in (n = 8): Complications: 5/8 (63 %)	Second look 48 h: (n = 44): Re-Bleeding: 5/44 (11%) Packing in h situ 48 h (n = 44): Complications: 6/44 (14 %)	Second look 72 h: (n = 3): Re-Bleeding: 0/3 Packing in situ 24 situ 72 h (n = 20): Complications: 3/20 (15 %)
Cué et al. 1990 [19]	2b	21 patients with penetrating or blunt Liver trauma	Packing in situ 24 h (n = 7): Abscess: 2/7 (29 %)	Packing in situ 48 h (n = 6): Abscess: 2/6 (33 %)	Packing in situ 72 h (n = 8): Abscess: 3/8 (38 %)
Caruso et al. 1999 [13]	2b	93 patients with penetrating or blunt liver trauma	Second look < 36 h Re-Bleeding: 8/39 (21 %) Complications: 13/39 (33 %) Mortality 7/39 (18 %)	Second look 36-72 h (n = 39): (n = 24): Re-Bleeding: 1/24 (4 %) Complications: 7/29 (29 %) Mortality 7/24 (29 %)	
Sharp et al. 1992 [64]	2b	22 patients with penetrating or blunt Liver trauma	6 patients with septic Complications: Packing in situ 2.2 ± 0.4 (2-3) days	16 patients without septic Complications: Packing in situ 2.0 ± 1.0 (1-7) days	
Abikhaled et al. 1997 [1]	2b	35 patients with penetrating or blunt abdominal trauma	Packing in ≤ 72 h Abscess: 1/22 (5 %) Sepsis: 11/22 (50 %) Mortality 1/22 (5 %)	Packing in situ > 72 h (n = 22) (n = 13): Abscess: 4/13 (31 %) Sepsis: 10/13 (77%), Mortality 6/13 (46 %)	

Definitive Abdominal Wall Closure

Key recommendation:

3.16	Recommendation	New 2016
GoR B	When a laparostoma is placed, definitive closure should be aimed for as soon as possible.	

Explanation:

Hatch et al. [33, 34] performed a retrospective analysis of the clinical histories of 925 consecutive trauma laparotomies, of whom 282 (30 %) were performed within a DC framework. Of these, 247 (88 %) survived until the second look operation; fascial closure was carried out in 86 (35 %) of these patients at this point. In 161 cases (65 %), definitive fascial closure was performed or attained at a later point. In the group with early fascial closure, there was a decreased complication rate in the further clinical course. Both groups were comparable, particularly regarding ISS and early laboratory and vital parameters. Thus, the authors concluded: "The current data demonstrate quite convincingly that early fascial reapproximation is associated with a significant decrease in complications and organ failure. Therefore, we recommend DCL in only the sickest subset of patients, optimization of open abdomen management, and fascial closure at the earliest possible time."
Multivariate analysis of both groups showed that the use of a vacuum system already at the time of DC laparotomy was an independent factor for successful early fascial closure (odds ratio 3.1; 95% CI: 1.42-6.63; p = 0.004) [33].
In an older systematic review study, the results of case series were summarized [10]. After that, the Wittmann patch is associated with the highest rate of success for abdominal wall closure. A retrospective cohort study achieved similar results [74]. In a small randomized study, there was no difference between temporary closure with vacuum dressings and polyglactin 910 mesh [8].
The ideal technique for fascial closure after laparostoma is not yet clear. Analysis of publications to date makes it obvious that in addition to heterogeneity of the investigated patient groups, there are also marked procedural differences among studies. There are almost no multi-center studies. Most results come from retrospective, mono-center studies. The current level of evidence is thus insufficient and leaves many unanswered questions.
In order to improve the data and thus, the quality of care in Germany, a laparotomy register has been implemented by the German Society for General and Visceral Surgery (DGAV).

Non-Operative Management of Blunt Liver or Spleen Injuries

Key recommendation:

3.17	Recommendation	New 2016
GoR B	In hemodynamically stable patients with isolated blunt liver or spleen injury, the goal should be non-operative management.	

Explanation:

The undisputed standard of care for isolated liver and spleen injuries in children after blunt trauma is non-operative management with intensive care supervision and readiness for immediate interventional radiology and/or surgical care.
In recent years, there has been a trend emerging to treat adults conservatively as well in cases where the injury is isolated blunt trauma and the patient is hemodynamically stable; some authors consider this the standard of care [35, 36, 65].
According to Hommes et al. [36], the conditions for non-operative management are hemodynamically stable patients with positive response to volume replacement as well as CT excluding other intra-abdominal injuries requiring surgery (e.g. bowel perforation).
After implementation of a damage control resuscitation protocol, Shresta et al. [65] found an improved success rate of operative management even of higher grade relevant blunt liver injuries.

Angioembolization

Key recommendation:

3.18	Recommendation	Modified 2016
GoR B	If contrast-enhanced CT shows evidence for an arterial bleed in a hemodynamically stable patient with liver injury, selective angioembolization when possible or laparotomy should be performed.	

Explanation:

Interventional radiology has a fixed place in polytrauma management and is used both as definitive therapy for organ and vessel injuries and in combination with operative management (before, after, or hybrid surgery) [21, 45].
When there is evidence of active bleeding on the contrast-enhanced CT that cannot or must not be addressed surgically, and there is good response to fluid and blood replacement in the ED, angioembolization can contribute to sustained hemodynamic stabilization and thus, can represent a key maneuver for definitive therapy [6, 31].

There are still no randomized studies. The best available evidence to date continues to suggest that angioembolization for blunt and penetrating liver injuries as a supplement to DC management decreases mortality compared to surgery alone (common RR [fixed effects] 0.47, 95% CI: 0.28 – 0,78) [4, 6, 39, 49, 50, 73]. The lack of multivariate adjustment and resulting bias must be considered. It is not currently possible to answer the question of whether angioembolization for liver injuries should be performed prior to or after DC laparotomy. Two studies advocate early neoadjuvant angioembolization because of lower complication rates [49, 73]. In two other studies, however, mortality was reduced when angioembolization was performed after DC laparotomy [50, 71].

The indication for endovascular intervention, surgery, or a combination of the two must be made carefully on a case-by-case basis. The decision must be made according to the rapid availability of an experienced interventional radiologist, the success of hemodynamic stabilizing procedures, intraoperative findings, and post-operative hemodynamics.

Key recommendation:

3.19	**Recommendation**	**Modified 2016**
GoR B	**For spleen injuries requiring intervention in hemodynamically stable patients, selective angioembolization can be performed instead of surgical hemostasis.**	

Explanation:

Angioembolization of the spleen has similar considerations to that of liver injuries.

The data available at the time that the previous version of this guideline called for restraint [18, 22, 32, 66]. Publications from the years 2005-2008 comparing angioembolization to conservative management found neither decreased treatment failure rates (common RR [random effects] 1.13; 95% CI: 0.86 – 1.48) nor reduced mortality (common RR [fixed effects] 1.19; 95% CI: 0.66 – 1.15). In the meantime, current data from Bhullar [9] and Miller [48] have identified positive effects of selective angioembolization, particularly in high-grade blunt spleen injuries. Here as well, the indication for endovascular intervention or for surgery must be carefully weighed on a case-by-case basis. The decision must be made according to the rapid availability of an experienced interventional radiologist and the success of hemodynamic stabilizing procedures.

Spleen-Preserving Procedures

Key recommendations:

3.20	**Recommendation**	**Modified 2016**
GoR B	**A spleen-preserving procedure should be aimed for in spleen injuries grade 1-3 severity on the AAST/Moore scale that require surgery.**	
3.21	**Recommendation**	**Modified 2016**
GoR B	**For adult patients with spleen injuries of grades 4-5 on the AAST/Moore scale that require surgery, splenectomy should be performed rather than an attempt at salvage.**	

Explanation:

The risk for "overwhelming post-splenectomy syndrome" (OPSI) is estimated at approximately 2.5 % [70]. Splenic injuries in hemodynamically stable patients are only seldom an indication for laparotomy. For the surgeon, the question of whether an organ can and/or should be preserved comes only after it has been determined that the patient needs surgery (e.g., for hemodynamic instability or increased transfusion requirements).

Heuer et al. [35] analyzed the database of the DGU Trauma Registry and found that patients treated with conservative spleen-preservation had lower systemic infection rates than patients undergoing splenectomy. The same analysis recommended that Grade 1-3 injuries should be preserved and that indication for operation is a Grade 4 or 5 injury in an adult together with hemodynamic instability and high transfusion requirements [35].

As expected, direct comparison of the results after splenectomy and salvage procedures is difficult to make because of the various patient populations and injury grades. An analysis of the North Carolina Trauma Registry of the years between 1988 and 1993 reported a trend toward primary non-operative management and abandonment of splenectomy with a stable frequency of splenorrhaphy. Unsurprisingly, comparison between the methods yielded decreased mortality after splenorrhaphy versus splenectomy (RR 0.36, 95% CI: 0.18-0.73) in cases of moderate ISS in the splenectomy group (25 $\pm$ 12 vs. 19 $\pm$ 11, $p < 0.001$) [16]. In this cohort, there were ten patients with an average ISS of 33 $\pm$ 15 in whom the salvage procedure failed. Two patients died after splenectomy. In another study of patients with comparable severity of injury, there were significantly fewer infections after splenorrhaphy (RR 0.30, 95% CI: 0.13-0.70) [28]. In another study, there was a non-significant trend for overall higher complication rates after splenorrhaphy (RR 1.81; 95% CI: 0.36-9.02) despite reduced injury severity [42].

In a series of 326 patients from the early 1980s, the rates of spleen-preserving procedures for Moore I/II, III, and IV/V injuries were 88.5%, 61.5%, and 7.7% [24]. A similar trend in relation to ISS was also demonstrated in a more recent study including 2258 adult patients [38]. The failure rate (re-bleeding, secondary splenectomy) after salvage procedures was 7 of 240 (2.9 %; 95% CI: 1.2-5.9 %). Splenectomy was necessary for 66.4 % of all patients with ISS $\geq$ 15. In a multivariate analysis of 546 patients over a 17-year period, Carlin derived injuries of grade 4 and 5 in adult patients as independent predictive variables for splenectomy [12]. In children, preservation of the spleen is a goal even in Grade 4 and 5 injuries.

Penetrating Hollow Organ Injuries

Key recommendation:

3.22	Recommendation	Modified 2016
GoR A	**Penetrating colon injuries must be controlled by suturing or resection to reduce the risk of intraabdominal infections.**	

Explanation:

Penetrating colon injuries pose a potentially life-threatening situation because of contamination of the sterile peritoneal space with mixed anaerobic flora. Thus, patients with abdominal gunshot wounds requiring immediate surgical treatment have a 100-fold higher risk of death than patients with injuries that can be treated non-surgically or in a secondary procedure [72].

Since 1979, six published randomized controlled trials (RCTs) have compared outcomes after primary continuity-preserving procedures versus temporary ileostomy insertion while leaving the injured intestinal segment [14, 23, 30, 41, 60, 67]. These studies were summarized in a 2009 Cochrane review [51]. The trends observed there were also reproduced in the multi-center study of the American Association for the Surgery of Trauma (AAST) [20].

Based on the best available evidence, there is a non-significant trend for improved mortality when primary anastomosis is performed (RR 0.67; 95% CI: 0.31-1.45), and a marked reduction in complication rates (RR 0.73; 95% CI: 0.52-1.02). It is possible that the risk for intra-abdominal infection is reduced by 23 % in cases of primary anastomosis (RR 0.77; 95% CI: 0.55-1.06); however, there is no clear evidence from an appropriately designed randomized study.

During the initial trauma laparotomy of a DC sequence, primary anastomosis is not indicated; here, the focus is on bleeding control and contamination prevention.

The evidence table for this chapter is found on page 287 of the guideline report.

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3.5 Traumatic Brain Injury

Operative Management

Emergency Operative Management

Key recommendation:

3.23	Recommendation	2016
GoR A	**Space-occupying intracranial injuries must be treated as a surgical emergency.**	

Explanation:

The goal of TBI therapy is to limit the magnitude of secondary brain damage and to provide optimal conditions for the functional regeneration of the neurons that have been functionally injured but not destroyed. Injuries requiring surgery must be treated promptly.

Indications for surgical decompression of a traumatic intracranial space-occupying lesion has never been verified in prospective randomized controlled studies. The benefits of operative decompression can be derived from several retrospective analyses [6-10, 17]. Due to decades of consensual experience, the need for surgical intervention can be considered a basic incontrovertible assumption of good clinical practice [14].

Space-occupying intracranial injuries are an absolute, urgent indication for surgery. This applies both for traumatic intracranial bleeds (epidural hematoma, subdural hematoma, intracerebral hematoma/contusion) as well as space-occupying impression fractures. The definition of space-occupying refers to a shift of cerebral structures, particularly the 3rd ventricle, which is normally located at the midline. In addition to findings on computed tomography (CT) (thickness, hematoma volume and location, magnitude of midline shift), clinical findings are crucial to the decision of whether and how rapidly operative intervention will take place. When there are signs of transtentorial herniation, minutes can determine the clinical outcome. It is not considered relevant to state particular volumes to determine whether a procedure is needed, because the individual situation of the patient (age, preexisting cerebral atrophy, etc.) must be taken into account.

Operations with Deferred Urgency

Open or closed impression fractures without a shift of the midline structures, penetrating injuries, and basal fractures with CSF leaks are operations with deferred urgency. These procedures require neurosurgical expertise. The timing of the operative intervention is dependent on many factors and must be determined individually.

Non-Operative Treatment of Intracranial Bleeding

In certain cases of non-space-occupying bleeding and stable neurological findings, non-operative management can be justified [8-10]. However, these patients must be closely observed both clinically and with CT. In cases of clinical deterioration or bleed expansion, immediate surgical decompression must be possible.

Measurement of Intracranial Pressure

Key recommendation:

3.24	Recommendation	Modified 2016
GoR B	**Measurement of intracranial pressure should be performed in unconscious patients with brain injury.**	

Explanation:

In recent decades, measurement of intracranial pressure (ICP) has found its way into acute management of unconscious TBI patients internationally and has been adopted by several international guidelines [2-4, 11, 14, 23]. This seems sensible for pathophysiological reasons, since clinical monitoring of many cerebral functions is limited. In sedated patients, it can indicate imminent midbrain compression secondary to progressive swelling or expanding intracranial hematoma and thus, enable early countermeasures to be implemented. Although to date there have been no prospective randomized controlled studies comparing clinical results related to use of ICP monitoring [18], several prospective as well as registry cohort studies [5, 16, 19, 22, 23, 29] in recent years have reported positive effects of ICP measurements on the overall course and outcomes. The much-discussed work of Chesnut et al. [12] did not find this positive association compared to close clinical monitoring and regular CT scans; however, in addition to the diverse criticism regarding the study's methodology, there is a question as to how well these results from Bolivia and Ecuador relate to our standard of care. For example, fewer than half of the patients were brought to the hospital in an official ambulance. The introduction of guidelines, which include ICP monitoring, also led to more favorable outcomes for TBI patients [15, 25].

ICP measurement is used for monitoring and as a guide to the management of unconscious TBI patients, considering the clinical course and the morphological findings on imaging. However, it is not necessary for every unconscious patient. ICP monitoring is also unnecessary in patients with hopeless prognosis and no meaningful therapeutic alternatives.

Adequate cerebral perfusion requires sufficient cerebral perfusion pressure (CPP), which can be easily calculated as the difference between the mean arterial blood pressure and mean ICP. The literature offers different answers to the question of whether the focus of treatment for increased ICP should be to decrease ICP or to maintain CPP. Evidence available to date suggests on the one hand that CPP should not fall below 50 mmHg [1, 3], and on the other hand that it should not be raised through aggressive therapy to over 70 mmHg [1, 3].

Continuous CPP determination requires invasive ICP measurement. As long as the ventricles are not completely compressed, ICP monitoring via a ventricular drain offers an alternative to lower ICP through cerebrospinal fluid drainage.

The determination of the individual optimal CPP requires understanding of cerebral perfusion, oxygen supply and demand, and/or brain metabolism. Regional measurements (with parenchymal sensors, transcranial Doppler examinations, or perfusion-weighted imaging) to estimate this value are the subject of scientific investigations [21, 28], but are not yet part of routine clinical practice.

Decompressive Craniectomy

Key recommendation:

3.25	Recommendation	New 2016
GoR 0	**Operative decompression with craniectomy and expansive duraplasty can be performed when there is increased cerebral pressure.**	

Explanation:

An effective alternative for lowering elevated intracranial pressure is surgical decompression by craniectomy and expansive duraplasty, if necessary. The need for this generally arises from the development of pronounced (secondary) cerebral edema and thus, frequently appears after a delay of several days. According to a prospective randomized controlled study, the method has shown good treatment success despite an increased complication rate [26]. Further prospective studies [13, 20, 24] are ongoing, with interpretation of clinical results the subject of current debate, and thus, no conclusive recommendation can be given [27].

For additional considerations, please refer to the updated Guideline for Traumatic Brain Injury in adults [14].

The evidence table for this chapter is found on page 316 of the guideline report.

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3.6 Genitourinary Tract

Key recommendations:

3.26	**Recommendation**	**2011**
GoR B	**The most severe kidney injuries (grade V on the AAST classification) should be surgically explored.**	
3.27	**Recommendation**	**2011**
GoR B	**For hemodynamically stable kidney injuries < grade V, primary conservative management should be initiated.**	
3.28	**Recommendation**	**2011**
GoR 0	**If other injuries make laparotomy necessary, moderate kidney injuries of grades III or IV can be surgically explored.**	

Explanation:

The need to perform surgical exploration of renal trauma is determined by hemodynamic instability, blood loss and transfusion requirements, serum creatinine, and the grade of injury severity [61]. The decision can also be influenced by the decision of whether to observe or explore other abdominal injuries [34].

Hemodynamic instability presents an absolute indication for exploration [49, 63]. Other indications are expanding or pulsatile peri-renal hematomas > 3.5 cm, contrast medium extravasation, and grade IV-V renal trauma [49, 63]. The goal of operative exploration of renal trauma is first hemostasis, if possible with suture of the defect (renorrhaphy) and drainage of the peri-renal hematoma or urinoma if necessary.

The decision to operate is based, among other things, on the revised classification of kidney trauma according to Moore et al. and Buckley et al. [11, 48]:

Table 23: Grading Classification of Renal Trauma according to Moore and Buckley [11, 48]

Grade	Pathological/Anatomical/Radiological Findings
I	Renal contusion or
	subcapsular hematoma (not expanding),
	no parenchymal lesion
II	non-expanding peri-renal hematoma,
	cortical parenchymal tear < 1cm deep, no extravasation
III	cortical parenchymal tear > 1 cm deep, no extravasation
IV	Parenchymal injury through the corticomedullary border involving the collecting system,
	shattering of the parenchyma or
	arterial or venous vascular injury of a segment with hematoma
V	Vascular injury of the renal hilum

In 2011, the American Association for the Surgery of Trauma amended the classification from 1989 [11]. Stages I-III remained unchanged [11]. Extensive parenchymal injury with shattering was moved from Stage V to Stage IV, and Stage V kept only injuries (laceration, avulsion, or thrombosis) of the renal hilum [11].

Single-shot pyelography can be performed intraoperatively to document the function of the contralateral kidney [49]. The usefulness of prior surgical control of the hilar vessels (with vascular clamp or vessel loop) is debated [3]. If hemodynamically unstable patients undergo explorative surgery, this generally leads to nephrectomy [4, 44].

Exploration rate is currently at approximately 10-15 % and should continue to fall as more centers push conservative measures for renal trauma [30, 43]. Most studies prefer a transperitoneal approach for surgical exploration [58, 59]. The renal hilum is then reached through the posterior parietal peritoneum, which is incised medial to the inferior mesenteric vein [59].

Temporary clamping of the renal hilum prior to the opening of the renal fascia and subsequent exploration and reconstruction is safe and effective [13, 42]. Temporary clamping ensures decreased intraoperative blood loss and yields lower nephrectomy rates [59].

Key recommendation:

3.29	**Recommendation**	**2011**
GoR 0	**Selective angioembolization of a renal vascular injury can be attempted as therapy in hemodynamically stable patients.**	

Explanation:

Advances in interventional radiology have significantly influenced the management of renal trauma over the past decade. Angiography with selective embolization is now the most important alternative to surgical exploration, provided there is no other indication for laparotomy [63]. Until now, the usefulness of angiography was limited by the few documented case series and case reports and by restricted use for only secondary or isolated trauma situations [23, 40]. Most of these had to do with branches of the renal artery to be embolized. There is no dispute that the selection of patients, technical equipment, and experience of individual medical practitioners involved have a decisive influence on the success rate. However, the above-mentioned case series reported very promising rates of successful hemostasis in over 82 % of cases, so that it is currently recommended that hemodynamically stable patients with third or higher grades of renal trauma undergo angiography with subsequent embolization [23, 29, 40].

The following findings on computed tomography are considered indications for angiography [63]:

- pronounced extravasation of contrast medium,
- large devascularized renal segments,
- grades IV-V renal trauma,
- arterial lacerations,
- avulsions,
- global or segmental hypoperfusion of the kidney,
- aneurysms,
- renal vein thrombosis,
- bleeding from a segmental or sub-segmental artery [63].

Peri-renal hematomas compressing the kidney and restricting perfusion are also indications for angiography [53]. Angiography is also important in the clinical course after primary laparotomy, for example in cases of persistent hematuria, with comparable success rates to the initial intervention [33].

The most common injury of the renal artery is dissection and subsequent occlusion [49]. Bleeding from the renal artery often stops spontaneously because of a tamponade effect by the hematoma within the renal fascia [49]. An injury to the renal fascia produces a retroperitoneal hematoma. For expanding hematomas, often the only alternatives are endovascular embolization or laparotomy [26].

The success rate of embolization for renal trauma is currently at 65 %, and angiography in cases of blunt trauma and hemodynamically stable patients at approximately 95 % [10, 15].

Although injuries to the renal hilum often require surgical intervention, endovascular therapy options have increased in importance. For example, renal artery embolization can be performed in cases of severe polytrauma or increased intraoperative mortality risk; on the one hand, it is a definitive therapeutic alternative, and on the other hand, nephrectomy can be performed after a delay during which the patient's condition is stabilized [63].

Caution is required in cases of fourth and fifth grade renal trauma, because success rates are markedly lower, and they may require more subsequent embolizations [63]. Nevertheless, embolization is safe and associated with few side effects [15]. Patients who do not require immediate surgical exploration can benefit from angiography and embolization without the increased risk of nephropathy that occurs with the additional contrast medium applied for arteriography [60].

Key recommendations:

3.30	**Recommendation**	**2011**
GoR 0	**According to the type and severity as well as concomitant injuries, kidney injuries can be surgically treated with suturing and partial renal resection if necessary, and other salvage measures.**	
3.31	**Recommendation**	**2011**
GoR B	**Primary nephrectomy should be reserved for grade V injuries.**	

Explanation:

In hemodynamically stable patients, parenchymal reconstruction is generally possible [63]. Nephrectomy is mainly reserved for patients with penetrating injuries, with high transfusion requirements, hemodynamic instability, and higher injury severity scores (ISS) [19]. Mortality is usually associated more with the overall severity of the polytrauma than with the renal injury [63].

In the case of high-speed projectile injuries, reconstruction is difficult and typically nephrectomy is the consequence [63].

If reconstruction is possible, renorrhaphy is the most common reconstructive technique [59]. In cases of parenchymal necrosis, a secondary partial resection may be necessary [63].

If the renal collecting system has been breached, either from trauma or from iatrogenic causes, it can be surgically closed when appropriate [45]. Alternatively, a shunt can be placed with a single-J or double-J catheter. A capsule defect can be covered with an omental flap-plasty, perirenal fat, or a hemostatic matrix [59]. A retroperitoneal drain should always be placed to remove any possible urine leakage [63].

Injuries of the renal hilum are generally associated with extensive trauma and are accompanied by increased morbidity and mortality rates [63]. It is extremely rare that reconstruction of fifth grade injuries of the hilum is possible, but it should be attempted in patients with a single kidney or in cases of bilateral injuries [63]. In these cases, generally a primary nephrectomy is sought [63].

Ureter Injuries

Partial ureter injuries can be defined as first and second grade injuries [47]. After initial diagnosis, minor grade injuries should be treated with ureteral stents or percutaneous nephrostomy catheters [64]. Ureteral stents, placed antegrade or retrograde, stabilize the leak and prevent stricture formation. Ureteral stents should remain for three weeks [64, 67].

Particularly in cases of delayed diagnosis, percutaneous nephrostomy placement is recommended as primary management; through these, antegrade stent placement is possible either at the time of nephrostomy or after a delay of 2-7 days [67].

Retrospective comparative studies have certified that antegrade treatment has a higher chance of success and is more easily carried out [64]. This applies particularly in higher grade injuries (grades II-III) [64]. When the stent is successfully placed, open operative treatment is necessary only in cases of persistent paravasation or stricture [64].

If grade II to III injuries are detected during open exploration, primary suture can be performed after stent placement [64]. Not even the smallest lesions created by gunshot or stab wounds should be treated with primary suture, since debridement is indispensable for stricture-free reconstruction [64].

Operative Therapy

The basic principles of operative care for ureteral injuries are debridement of necrotic tissues, spatulation of the ends with mucosa-to-mucosa anastomosis using absorbable suture, ureteral stent placement, and external drainage [39]. In principle, there are differences in the treatment for higher grade injuries, according to where the leak is located [39, 49, 59, 63, 64].

In the **upper third** of the ureter, alternatives are [49, 59, 63]:

- ureteroureterostomy,
- transuretero-ureterostomy,
- pyeloplasty,
- transposition of the renal vein,
- intestinal ureteral replacement,
- ureterocalicostomy, and
- nephrectomy as a last resort.

Defects of the **middle** and **lower thirds** of the ureter can be treated as follows [6, 59, 63]:

- creation of a Boari bladder flap and ureteral implantation,
- direct re-implantation of the ureter,
- ureteral implantation with psoas hitch,
- ureteral implantation with Boari bladder flap and psoas hitch if necessary.

Complete ureteral avulsions require ureteral replacement if ureteral re-implantation is not possible by the above-mentioned procedures because alloplastic material is not available. Here the kidney can be mobilized distally through transposition of the renal vein or autotransplanted to the iliac fossa [2, 7, 12].

Ureter replacement procedures can be performed using the ileum, the colon, or in exceptional cases Meckel's diverticulum [1, 22, 55, 62, 63].

Urinary Bladder Injuries

Key recommendations:

3.32	**Recommendation**	**2011**
GoR B	**Intraperitoneal bladder ruptures should be surgically explored.**	
3.33	**Recommendation**	**2011**
GoR 0	**Extra-peritoneal bladder rupture without bladder neck involvement can be treated conservatively with a suprapubic urinary catheter.**	

Explanation:
In most cases, the often numerous concomitant injuries in multiply injured patients are treated with more priority than bladder injuries. According to statistics, extraperitoneal injuries occur about twice as often as intraperitoneal bladder ruptures [17, 31]. Much more seldom are combination injuries with extra and intra-peritoneal ruptures [54]. In principle, management is differentiated according to blunt and penetrating injuries as well as intra- and extraperitoneal bladder ruptures.

Blunt Trauma

Extraperitoneal Bladder Injury
Uncomplicated bladder injuries (grades I-III) can generally be treated with a transurethral catheter, regardless of whether there is large perineal or scrotal extravasate [28, 66]. Exceptions are injuries to the bladder neck, bone fragments in the bladder wall, incarceration of the bladder wall, or concomitant injury to the rectum (grade V), which should be treated surgically [28, 66]. In cases of operative exploration for other injuries, an extraperitoneal bladder rupture should also be treated operatively, to minimize the risk of infection [20, 69].

Intraperitoneal Bladder Injury
Intraperitoneal bladder injury (grades III-V) should receive primary operative treatment due to the risk of peritonitis or sepsis and the high associated mortality [28, 66, 69].

Penetrating Trauma
In case of penetrating bladder injury, immediate operative exploration should be performed [16, 66]. The recommended approach is a midline cystostomy, where the bladder wall can be inspected, and the bladder neck as well as the distal ureters can be examined for associated injuries [16, 28].

Large Surface Bladder Injuries
In case of a large bladder wall defect, such as involvement of the bladder when there is detachment of the lower abdominal wall or the peritoneum, if necessary a bladderplasty, for example with a myocutaneous flap or another option, can be performed [28, 71].

General Intra and Post-Operative Management
If possible, two-layered mucosa-detrusor closure with resorbable suture is recommended for surgical treatment [28, 70].
Post-operative bladder catheterization lowers intravesical pressure and facilitates tension-free wound adaptation [70]. Depending on the type and scope of injury, a 7-14 day duration of catheterization is recommended [28, 70].
Prior to removing the bladder catheter, retrograde cystography should be carried out whenever possible [28, 70]. If there is evidence of contrast medium extravasation, the catheter can be kept for another seven days and re-cystography performed [28, 70].

Urethral Injuries

Key recommendations:

3.34	**Recommendation**	**2011**
GoR B	**Complete rupture of the urethra should be treated in the primary operative phase with a suprapubic catheter.**	
3.35	**Recommendation**	**2011**
GoR 0	**The urinary catheter can be supplemented with a urethral stent.**	
3.36	**Recommendation**	**2011**
GoR B	**If pelvic fracture or other intraabdominal injuries make surgery necessary, urethral ruptures should be treated at the same time.**	

Explanation:
When treating urethral injuries, it is particularly worth mentioning that the approach presented here refers explicitly only to the primary operative phase, because some other principles apply for further care.
To this point, it has not yet been sufficiently verified whether primary, delayed, or secondary re-anastomosis is preferable in cases of complete rupture of the posterior urethra. Chapple et al. suggest primary and delayed stenting of the urethra [14]. The main problems in the posttraumatic course are urethral strictures, incontinence, and impotence, so avoiding these is the goal of therapy.
In a literature review summarizing several case series and comparative studies on the treatment for urethral ruptures, Koraitim reported the following rates of stricture, incontinence, and impotence. For suprapubic catheterization alone they were 97 %, 4 %, and 19 %; for primary stent placement rates were 53 %, 5 %, and 36 %; and for primary closure they were 49 %, 21 %, and 56 % [18, 24, 25, 27, 35-37, 50]. Correspondingly, in cases of complete urethral rupture in men, he recommends suprapubic catheterization or stent placement for larger gaps between the urethral ends [36]. In a more recent study by Ku et al., both alternatives were also considered comparable [38]. The EAST guideline came to a similar conclusion that both primary stent placement and suprapubic catheterization with secondary surgery are equally worthy of recommendation [32].
In cases in which an operation is already required because of adjacent injuries, it might be advisable to treat the urethral rupture directly in certain situations, to avoid a second procedure [8]. Especially when there is contamination of the abdominal cavity from colon injuries, primary closure of the urethra over a stenting catheter seems appropriate, to avoid a complicating infection [9]. Even in cases when a

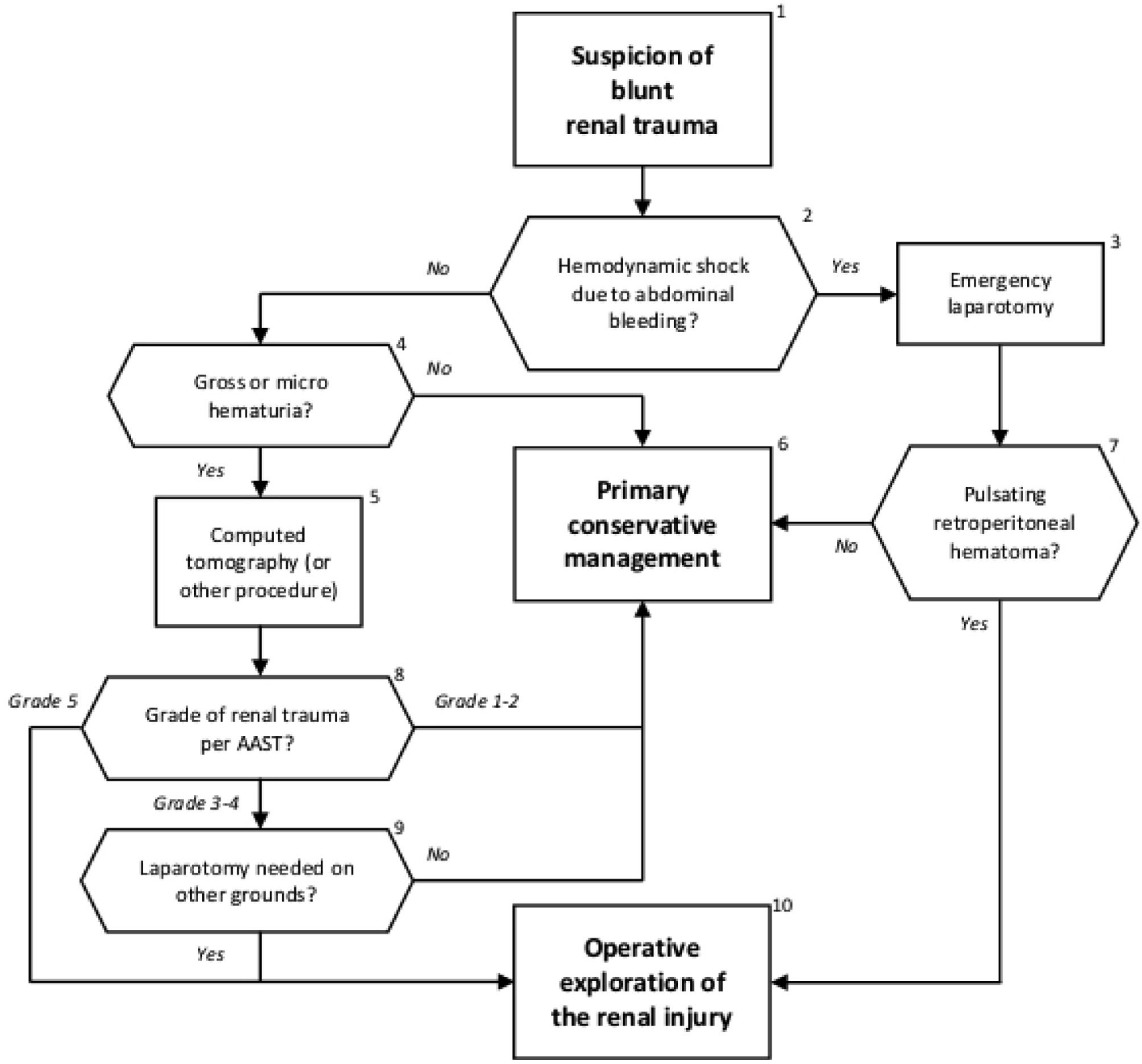
conservative approach appears possible, urethral injuries can be treated with primary surgery if definitive osteosynthesis of the bony pelvis cannot be performed without it [41].

Rupture of the anterior urethra in males are somewhat less common than of the posterior urethra [9]. Primary operative reconstruction can be necessary in cases of open injuries. In the majority of cases, however, preference should also be given here to suprapubic catheterization and delayed reconstruction, since reconstruction of the anterior urethra and the external male genitalia, which are often concomitantly affected, is usually difficult and time-consuming [14]. However, in cases of penis fracture with injury to the corpus spongiosum, it is recommended that the urethral injury also undergo primary surgery [14, 51]. The severity of the urological injury and the severity of the injuries overall are crucial to the selection of primary operative versus conservative management [14, 46].

Urethral injuries are significantly less common in female patients compared to men. When they do occur, however, they are very pronounced and associated with bladder injuries [14]. For this reason, primary treatment should consist of suprapubic catheterization alone, assuming that the patient is hemodynamically unstable and/or other injuries require more urgent operative care [68]. On the other hand, for women with less severe polytrauma, ruptures of the proximal urethra can undergo primary reconstruction through a retropubic approach [5, 52, 65].

These recommendations generally apply to children, with whom a similar distinction should be made according to gender. In a series of 35 boys with posterior urethral tears, Podestá et al. 1997 compared suprapubic catheterization (with later urethroplasty), suprapubic catheterization with catheter splinting of the urethra, and primary anastomosis [57]. Since the continence rate after primary anastomosis only reached 50 %, and ten patients in the catheter splinting group eventually required urethroplasty, the authors recommended suprapubic catheterization with delayed secondary urethroplasty [57]. In a study of urethral injury in girls with pelvic fractures and other concomitant injuries, the same authors found the most advantage for delayed treatment, since good results were observed despite accompanying bladder and vaginal injuries [56].

Figure 11: Algorithm for the Diagnostic and Therapeutic Procedure for Suspected Kidney Injuries [21]



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3.7 Spine

Indications for Surgery

Key recommendation:

3.37	**Recommendation**	**2011**
GoR B	**Unstable spinal injuries with verified or assumed neurological deficits, with deformities, in whom the reduction, decompression and stabilization procedure appears to have halted or improved neurological symptoms, should be treated surgically as soon as possible ("day 1 surgery").**	

Explanation:

Regarding the order of treatment priority, spine injuries come in third place after life-threatening injuries to the body cavities and the head as well as the large long bones, or in second place in the presence of spinal cord injury [36].

The indications for surgery include atlanto-occipital dislocation, translational atlanto-axial dislocation, unstable Jefferson fracture, unstable dens fracture (especially type II), Hangman's fracture (pars interarticularis fracture C2 and disc injury C2/C3), C3-C7 fractures (A3, B, and C types) also in terms of dislocation, and T1 to L5 fractures (A3, B, and C types) also in terms of dislocation. According to prevailing opinion, there is also an absolute indication for surgery when there is an open spine injury [19, 51].

Also useful in establishing indications for primary management of spine injuries in polytrauma is to classify according to a) complex spine injuries with injury to essential neural pathways and organs such as spinal cord, lungs, large vessels and abdominal organs, b) unstable spine injuries (types A3, B, and C), in whom functional management can lead to severe deformity and neurologic damage, and c) stable spine injuries according to Blauth et al. 1998. If complex or unstable spine injury is present, operative stabilization should be sought as soon as possible–on the day of the injury if none of the contraindications listed below is present [8].

According to Blauth et al. 1998, a complex spinal injury is a multi-level spinal injury or one accompanied by concomitant intra-thoracic or intra-abdominal injury or by polytrauma. That polytrauma "creates" a complex injury is substantiated by, among others, the studies of Hebert and Burnham [26], who determined that hospital stays are longer and the number of surgeries increased in these patients, and that the combination of spine injury with multiple trauma is associated with higher morbidity and mortality as well as increased degree of disability. Nevertheless, according to a North American survey by Tator et al. 1999, one third of spine injuries with neurologic damage were still treated conservatively and only 60 % of operations were performed before the 5th day, with 40 % afterwards [60].

The goal of primary operative management in unstable spinal injuries with confirmed or assumed neurologic deficits or with deformity is first, early spinal decompression while avoiding secondary neurologic damage and second, to achieve stability for positioning maneuvers during intensive care [36].

The surgical indication to avoid neurologic damage is relatively clear in unstable fractures without a spinal cord lesion. If there are unstable spinal injuries that could be displaced during positioning maneuvers such as during treatment for chest trauma, there is an indication for primary operative stabilization [8, 13, 29, 67]. If there is a contraindication, the goal should be stabilization and decompression at the earliest possible time. This was confirmed by Fehlings et al. [23]. Here, the recommended goal is decompression within the first 24 hours. Our data shows significant improvements in neurological symptoms according to the ASIA protocol when decompression and stabilization are performed within the first six hours. Animal studies have found benefits regarding neurological symptoms for the earliest possible spine stabilization [18, 20].

La Rosa et al. [39] and Fehlings et al. [23] found benefits for early operative decompression versus later decompression or conservative therapy. In the early group (17 hours) there was an improvement in neurological symptoms in 42 % of the patients with complete deficits, and 90 % of patients with incomplete deficits. Improvement rates were 8 % and 59 % in the delayed stabilization group, and 25 % and 59 % in the conservative management group.

The only randomized controlled study on this topic included 62 patients with isolated cervical spine injury [59]. Although the authors found no difference in neurological results for earlier (< 72 hours) versus later (> 5 days) stabilization, they recommended earlier stabilization. Levi et al. also reported indifferent results regarding earlier (< 24 hours) and late (> 24 hours) stabilization of cervical spine injuries, but also ultimately recommended the earlier procedure [62]. Wagner and Chehrazi also found no correlation between time of surgery and neurological symptoms, and concluded that primary medullary damage determines prognosis [65]. However, other studies related to primary and secondary damage show that secondary damage is not negligible and that patients benefit from avoiding it [3, 70]. McKinley et al. draw a similar conclusion [44]. However, Papadopoulos et al. found better neurological results after earlier surgery [47]. In 1999, Mirza et al. also reported that early stabilization (< 72 hours) had more favorable neurological outcomes than later stabilization (> 72 hours) [46]. All of these are data from studies not exclusively investigating polytrauma patients.

In addition to the studies focusing primarily on neurological outcomes, there are a number of studies focusing on non-neurological effects of earlier stabilization. A 2001 study by Croce et al. found evidence that early stabilization (< 3 days) of thoracic spine injuries in polytrauma (average ISS 24) decreased intensive care duration, pneumonia rate, costs, and time of mechanical ventilation compared to later stabilization (> 3 days) [13]. Johnson et al. [29] also found a benefit for primary stabilization of unstable spine fractures, with a decreased rate of ARDS in multiply injured patients. Similarly, Dai et al. found reduced pulmonary complications after early treatment [15]. According to the results of Aebi et al. [1], immediate operative treatment of cervical spine injuries is more important for neurological outcomes than improved operative techniques. In a 2005 study, Kerwin et al. [30] found that primary stabilization of the spine in severely injured patients (ISS > 25) shortened hospital stays from 29 to 20 days.

The indications listed above are based on an assumption that the injury has undergone adequate assessment and diagnosis in the emergency department. The patient should be hemodynamically stable, and surgical causes of bleeding should be excluded. Additional vital parameters such as intracranial pressure, core body temperature, and coagulation should be in the normal range. If there is reasonable risk that primary reduction, decompression, and stabilization of the spine would significantly worsen the patient's condition, a spinal stabilization procedure is relatively contraindicated.

If their condition is stable according to intracranial pressure, respiratory, and hemodynamic parameters, multiply-injured patients benefit particularly from early management of spine injuries; there is stability for positioning maneuvers, and secondary "hits" from subsequent procedures can be avoided. In addition, the antigenic load created by an unstable fracture in close proximity to the trunk can be reduced. On the other hand, critical conditions such as hypothermia, mass transfusion, coagulopathy, pulmonary insufficiency, and higher catecholamine dependency are relative contraindications for immediate spinal stabilization.

In this context, McLain and Benson 1999 [45] found that immediate (<24 hours after trauma) stabilization achieved the same outcomes as early (24-72 hours after trauma) stabilization of an unstable spine fracture in patients with multiple injuries, neurological symptoms, and concomitant thoracoabdominal injuries. Nevertheless, the authors recommend stabilization at the earliest possible opportunity. Schlegel et al. [57] and Chipman et al. [12] reported that operative stabilization of unstable spine fractures within 72 hours was associated with decreased morbidity (fewer pulmonary complications, fewer urinary tract infections, shorter hospital and intensive care stays) in polytrauma patients. When an abdominal injury is present, which leads to laparotomy in 38 % of patients with spine fracture [6], the decision of whether an unstable spine fracture must or can be stabilized during the same operative session must be made after the abdomen has been treated.

In contrast, for cases of hemothorax, the presence of blood in the thorax itself supports early stabilization of an existing thoracic spine injury [16]. The results of Petitjean et al. [48] also support early stabilization of thoracic spine fractures for concomitant chest trauma with lung contusion among other things. If there is primary paraplegia or unreducible dislocation, the operation can be postponed until organ functions are stabilized with intensive care.

In conclusion, benefits for early surgery in polytrauma patients have been reported, particularly in recent publications from 2006 to 2010 [2, 4, 5, 11, 21-24, 31, 32, 43, 52, 54-56]. Early fracture stabilization and decompression enable favorable neurological shift, decrease general complications, and shorten hospital stays. Because general complications, particularly lung-related, occur frequently in polytrauma patients, the result is a recommendation for surgery to be performed as early as possible.

Key recommendations:

3.38	**Recommendation**	**2011**
GoR B	**Unstable thoracolumbar spine injuries without neurological symptoms should be treated operatively.**	
3.39	**Recommendation**	**2011**
GoR B	**Surgery should be performed on the day of the accident or later in the course of treatment.**	

Explanation:

Apart from B and C type injuries, this recommendation applies particularly to A2 and A3 type fractures of the thoracolumbar spine, which are not displaced by positioning maneuvers during intensive care. In such cases, there no reason for urgent stabilization on the day of trauma. However, according to Jacobs et al. [28], patients treated operatively for unstable thoracolumbar fractures have better outcomes regarding reduction, neurological symptoms, mobilization, rehabilitation times, and complication incidence than patients treated conservatively [69].

Key recommendation:

3.40	**Recommendation**	**2011**
GoR B	**Stable spine injuries without neurologic symptoms should be treated conservatively.**	

Explanation:

Fractures of type A1, and sometimes A2, are considered stable, and do not benefit from operative stabilization [50, 68], particularly when the adjacent intervertebral discs remain intact. Surgical stabilization for such cases is not recommended particularly in polytrauma [34].

Operative Technique

Key recommendation:

3.41	**Recommendation**	**2011**
GoR 0	**For injuries of the cervical spine, the following techniques can be used as primary operative method: 1. Halo fixation, 2. ventral stabilization procedure.**	

Explanation:

Halo fixation is indicated when there is a contraindication to necessary definitive internal fixation, and a soft cervical collar is not sufficient as a temporary stabilizing measure [10, 14, 25, 27, 33, 34, 37, 42, 50, 53, 64].

Ventral spondylodesis is indicated particularly in cases of C3-C7 fracture dislocations. As a rule, corpectomy is the procedure of choice, with removal of the disc, replacement with iliac crest bone graft or a cage if necessary, and stabilization with a plate, possibly with a fixed-angle [14]. Because of the bridging effect during fixation, the use of chips and locking plates has not yielded better healing [53]. In polytrauma patients, ventral management of unstable cervical spine fractures is preferable to dorsal stabilization procedures, particularly on the day of trauma [37]. According to Brodke et al. [10], there are no significant differences regarding bony consolidation, reduction success, neurological symptoms, or long-term complaints in ventral versus dorsal approaches to the C-spine; however, the latter is much more complex and time-consuming, which is why it should not be recommended in patients with multiple injuries. If there is an unstable dens fracture, ventral screw placement is generally indicated. If the patient is hemodynamically stable, a Magerl screw is preferable due to the lower rate of screw displacement. In cases of a Jefferson fracture, dorsal screws or occipitocervical fusion might be indicated. However, there is no good indication to perform the latter as day-one surgery and should be planned as an elective procedure at a later time.

Key recommendation:

3.42	**Recommendation**	**2011**
GoR B	**A dorsal internal fixator should be used as primary operative method for injuries to the thoracolumbar spine.**	

Explanation:

Only dorsally-placed internal fixation can be recommended as primary treatment of thoracolumbar spine fractures [35, 49, 58]. This procedure achieves good reduction, decompression, and stabilization, sufficient for all positioning maneuvers for intensive care. According to Kossmann et al., these measures are considered the damage control strategy for the spine in polytrauma [38]. When necessary, ventral fusion can be performed electively during the secondary operative phase. In addition, according to Been and Bouma, dorsal stabilization alone should be sufficient for burst fractures of the thoracic/lumbar spine [7]. Both logistical and technical effort as well as OR time must be considered for the various spine surgery methods.

Laminectomy increases instability [1, 17, 41, 61, 71] and at best can serve as access to slide posterior edge fragments forward during dorsal decompression. It is debated whether the removal of bony fragments from the spinal canal ("spinal clearance") is really clinically beneficial [9, 40, 66]. In this respect, the indication for laminectomy should be very narrow and considered only if there are neurological symptoms and compression caused by bone and disc fragments that cannot be removed from a ventral approach.

Regarding blood loss and post-operative pain, percutaneous insertion of the internal fixator for dorsal stabilization of the thoracic and lumbar vertebrae would be preferable to an open procedure. A study by Vanek et al. showed significant benefits for this. Screw malposition was not more frequently observed [63]. In cases of neurological deficits, however, an open approach is advisable, because laminectomy for decompression of the spinal cord must be performed.

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3.8 Upper Extremity

Key recommendation:

3.43	**Recommendation**	**2011**
GoR B	**Surgical management of upper extremity long bone fractures should be performed early.**	

Explanation:

Injuries of the upper extremity are common in multiply injured patients [1, 26]. At the current time, there are no prospective comparative studies that determine the optimal time point for operative treatment of long bone fractures of the upper extremity in polytrauma patients. Accordingly, the following are based on studies that have either analyzed shaft fractures of the lower extremity in polytrauma patients or that have evaluated a subgroup of a polytrauma patient population that has upper extremity long bone fractures.

Severe extremity injuries lead to increased operative interventions and prolonged duration of treatment [1]. Shaft fractures of the upper extremity must be treated operatively at an early stage, if possible directly after respiratory and hemodynamic stabilization [24]. If there are concerns regarding primary internal fixation, there are alternatives such as external fixators as well as primary casting and later approach change [32]. Even peri-articular fractures can be treated with initial external fixator or casting stabilization with a planned secondary procedure according to fracture type and additional injuries [5].

Operative treatment of open fractures includes stabilization measures on the one hand, and simultaneous soft tissue debridement on the other. These measures should be carried out within the first 6 hours if possible. The stabilization procedure (temporary vs. definitive) depends on overall patient condition and the severity of soft tissue injury.

Within the hierarchy of urgency of care, however, the existence of other fractures is also important. Thus, in general, the priority of upper extremity fractures in polytrauma patients is after torso and lower extremity injuries, if present, but before complex joint reconstructions, as well as the definitive treatment of maxillofacial injuries and soft tissue reconstructions. Specific concomitant factors (e.g. open fractures) can also require modifications to treatment priority [33].

There are no comparative studies specifically examining the most suitable operative approach for fractures to the upper extremity in patients with multiple injuries. However, because polytrauma patients are included together with patients suffering isolated injuries in heterogeneous groups of patients with long bone fractures of the upper extremity, analogies are generally drawn from this overall population. Large studies with corresponding high levels of evidence are also not available [19].

The focus for management of upper extremity fractures in polytrauma patients is on rapid and secure stabilization of the fracture. Within this context, there is debate regarding the importance of intramedullary nailing and plate fixation. In these cases, the surgeon's competence in a particular method seems to be more important the procedure-specific benefits and disadvantages [2, 5-8, 12, 23, 25, 34]. Specific intramedullary procedures have now come into use for metaphyseal fractures of the radius and ulna; there are no studies yet available regarding their use in multiply injured patients [10].

Key recommendations:

3.44	**Recommendation**	**2011**
GoR B	**The decision to amputate or to salvage a severely injured upper extremity should be made on a case-by-case basis. The local and overall condition of the patient plays a decisive role.**	
3.45	**Recommendation**	**2011**
GoR 0	**In rare cases and with extremely severe injuries, amputation can be recommended.**	

Explanation:

In cases of subtotal amputation injuries, fracture stabilization and reconstruction of nerves, vessels, and soft tissue should be performed immediately after the resuscitation phase and treatment of vital injuries, if necessary also while shortening the extremity. In cases of complete amputation injuries, the availability and condition of the lost extremity are key to deciding whether to perform replantation or definitive amputation for vital stump creation. Even a heavily contaminated, high-grade open fracture is not in itself an indication for primary amputation in polytrauma patients [15]. For these, stabilization and debridement are the main concerns [15, 17]. Most publications available on this topic are case reports [13].

Key recommendation:

3.46	Recommendation	2011
GoR B	**As far as the overall severity of injury allows, surgical management of vascular injuries should be performed as soon as possible, i.e. directly after treatment of life-threatening injuries.**	

Explanation:

The restoration of adequate perfusion to injured extremities has high treatment priority also for multiply injured patients. This is based on the recognition that ischemia duration has been verified as the decisive, surgery-influencing factor regarding poor outcomes for the affected extremity [14, 22, 28]. For injuries in which associated vascular injuries eventually required secondary amputation, the ischemia time exceeded 6 hours in 51.8 % of cases, there was a high degree of soft tissue damage in 81.4 %, and there was a third-degree open fracture in 85.2 % [28].

In cases of life-threatening situations, an individual decision can be made to postpone a reconstructive procedure if needed. Due to low case numbers, the only scientific evidence is in isolated case series [14, 22, 28].

The lack of palpable pulse of the affected extremity can be a crucial sign of fracture-associated but isolated vascular injury [28]. Doppler and duplex ultrasound can supplement other investigations; however, they have been reported as not sensitive enough to reliably exclude vascular injury [28]. Rather, the recommendation is for prompt pre-operative angiography in cases of even mild suspicion of vascular injury [28].

Key recommendation:

3.47	Recommendation	2011
GoR B	**Injuries with nerve involvement should be managed together with stabilization, depending on the type of nerve injury.**	

Explanation:

Adequate evaluation of potential nerve lesions is difficult, since multiply injured patients are often intubated and ventilated on arrival at the hospital. In addition, it is often difficult to perform an adequate and dedicated examination regarding the sensory and motor function of the fractured upper extremity at the accident scene. For these reasons as well, the incidence of peripheral, fracture-associated nerve lesions of the upper extremity is reported as between 1 and 18 % in the literature [4, 27].

If it is not a simple decompression within the context of fracture management, reconstruction of peripheral nerve lesions around the long bones of the upper extremity is considered time-consuming and complex. Thus, a planned procedure carried out under stable conditions is of priority [9, 16, 20, 21, 31]. This type of care should be integrated into the primary management of polytrauma patients only in exceptional cases. This holds true not only for injuries of individual peripheral nerves, but also to injuries of the brachial plexus [9, 16, 20, 21, 31]. Due to low case numbers, there are only isolated case series published that do not focus on polytrauma patients. Regarding outcomes, it is important to consider that these are multi-factorial and not determined exclusively by the time of surgery [11].

Compartment syndromes occur rarely in association with long bone fractures of the upper extremity. However, because of the damaging consequences that occur within a few hours, they require rapid decompression with fracture stabilization. This applies equally to multiply injured patients and isolated injuries, and should take place as soon as possible following the trauma and/or diagnosis of the compartment syndrome. In this case, prognosis depends on the overall scope of injuries. Thus, in this context, better outcomes have been demonstrated in isolated compartment syndromes without fracture [29, 37]. Nevertheless, the statement for rapid action comes more from experience of trauma care for the lower extremity than from specific studies examining compartment syndromes of the upper extremity in polytrauma.

In cases of pediatric polytrauma, fractures involving the epiphysis are an urgent indication for surgery once vital functions have been stabilized. Long bone shaft fractures are often treated with elastic intramedullary nails fixed outside the epiphyses [35], and external fixator placement is a recognized surgical alternative. Good healing results have been achieved using external fixators particularly for cases of open fractures as well as comminuted fractures [3]. However, it must still be considered that the scientifically reported case numbers are very small [3, 30]. Thus, in principle, it is recommended that the operative concept be adapted to child age as well as the concomitant injuries [18, 36]. Again here, due to the small number of cases there are only isolated case series available, which are not limited to polytrauma.

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3.9 Hand

Fractures and Dislocations of the Distal Forearm, Carpus, Meta-Carpus, and Phalanges

Key recommendations:

3.48	**Recommendation**	**2011**
GoR B	**Closed fractures and dislocations should preferably be treated conservatively during the primary operative phase.**	
3.49	**Recommendation**	**2011**
GoR A	**During the primary operative phase, dislocations must be reduced and immobilized.**	

Explanation:

In multiply injured patients, 75 % of hand injuries are closed fractures [1, 72]. In principle, closed fractures and dislocations can be easily reduced according to clinical criteria and immobilized by simple means (casts, splints). However, in unstable, extremely displaced fractures of the distal radius, metacarpus, and phalanges, primary stabilization with external fixator and Kirschner wires is indicated after closed reduction.

In the secondary phase (5th to 12th day), the following injuries should undergo definitive surgery: unstable fractures and fractures with intolerable deformity, ligament injuries and fractures treated temporarily during the primary operative phase.

Finger joint dislocations are important injuries regarding the prognosis for hand function. In principle, reduction should be performed immediately [18, 57]. If closed reduction is not possible, open reduction must be performed during the primary operative phase. After successful primary reduction, stable closed finger dislocations without articular fractures can be treated non-operatively [3, 18, 34, 53, 55, 76, 81, 99, 105].

Key recommendation:

3.50	Recommendation	2011
GoR B	**For open fractures and dislocations, primary debridement should be performed with subsequent wire or external fixator stabilization.**	

Explanation:

Open fractures and dislocations are to be treated during the primary operative phase. The main approach corresponds to the general procedure for open bony injuries (dressing opened only in the OR, wound lavage, debridement, irrigation, fracture stabilization, soft tissue reconstruction). Fracture stabilization with an external fixator or with Kirschner wires is preferable to time-consuming primary definitive plate or screw fixation [4, 11, 12, 29, 65, 78]. Wound irrigation and careful debridement are crucial to prevent infection [38, 88]. The need for a second-look procedure after 2-3 days depends on the primary local pattern of injury and on the clinical situation [38]. Regarding antibiotic administration, see the "Medical Therapy" section.

Key recommendation:

3.51	Recommendation	2011
GoR A	**For perilunar dislocation/fracture, reduction must be performed during the primary operative phase, open if necessary.**	

Explanation:

Long-term outcomes after perilunar/lunar dislocations depend on early diagnosis and appropriate treatment. Reduction of the dislocated carpal bones is performed closed early during the primary operative phase or if this is not possible, open. After primary closed or open reduction, stabilization with Kirschner wires and/or an external fixator must be applied [31, 43, 67, 74].

Definitive open reduction, internal fixation with drill wires, and/or reconstruction of the ruptured ligaments should be undertaken during the secondary phase. Fractures accompanying perilunar dislocation injuries should be fixed with screws or drill wires [30] [43, 46]. While injury morphology itself (characteristics of the fracture and dislocation lines, amount of displacement) is not important for the long-term clinical and radiological outcomes, the time to diagnosis and the accuracy and retention of the reduction are relevant prognostic factors [31, 43].

Amputation Injuries

Key recommendations:

3.52	Recommendation	2011
GoR A	**For decisions regarding replantation, overall injury severity must be considered and the principle "life before limb" applied.**	
3.53	Recommendation	2011
GoR B	**For this decision, local findings and patient-dependent factors should also be taken into account.**	

Explanation:

Replantations around the hand in polytrauma patients are possible and advisable, provided the severity grade is I-II (polytrauma score, PTS) [10, 87]. However, the indication for replantation should be kept very narrow in patients with life-threatening injuries, because the operative time increases significantly and with it, morbidity [9, 66].

Negative predictors are crush or avulsion injuries, severe contamination, warm ischemia over 12 hours or cold ischemia over 24 hours, arteriosclerosis, and smoking [2, 6, 9, 19, 25, 28, 37, 66, 73, 94, 95]. For replantations at the level of the wrist and further proximal, the serum potassium concentration measured 30 minutes after reperfusion of the amputated part can be used as a prognostic indicator (critical value 6.5 mmol/l) [100].

Key recommendation:

3.54	Recommendation	2011
GoR B	**As with isolated hand injuries, the goal should be replantation particularly in cases with loss of thumb, multiple fingers, or in amputations at the level of the metacarpus/carpus/wrist as well as all amputation injuries in children.**	

Explanation:

Injuries with priority for replantation are amputations of the thumb, multiple digits, metacarpals, and the wrist [9, 25, 35, 37, 66, 73, 101, 106]. Revascularizations have a somewhat more favorable prognosis, since the existing tissue bridges often improve venous return [70, 77].

Provided that the patient's overall condition allows it, the indications for replantation should be more liberal in children, because good functional results can be expected [22, 37, 70, 93, 107]. Positive predictors here are smooth amputation edges and body weight over 11 kg [5]. Fingers in children tolerate significantly longer ischemia times than adults [17].

Key recommendation:

3.55	**Recommendation**	**2011**
GoR B	**Individual finger amputations proximal to the superficial tendon insertion (base of the middle phalanx) should not be replanted.**	

Explanation:
The level of finger amputation is crucial to decide whether replantation is indicated. Because of the expected poor functional outcome as a result of severe movement restriction, replantation is not indicated when the amputation of an individual finger is proximal to the superficial tendon insertion [19, 94, 106]. In contrast, amputations that occur further distal are advisable provided that the dorsal veins can be reconstructed. Good results can be achieved with the distal phalanx even without venous reconstruction [16, 28, 36, 37, 50, 56, 89].

Complex Injuries of the Hand

Key recommendation:

3.56	**Recommendation**	**2011**
GoR A	**The decision to perform time-consuming hand salvage attempts is done on a case-by-case basis. The overall injury severity and the severity of the hand injury must be considered.**	

Explanation:
When there are complex hand injuries with involvement of bones, tendons, nerves, and skin, the additional strain on the patient by reconstruction must be weighed against the chances for successful outcomes and the expected functional gains. Time consuming salvage attempts in the hand region are only indicated in PTS severity grades of I and II [87]. The decision for or against hand preservation must always consider the individual circumstances of each patient. The MESS (mangled extremity severity score), originally developed for the lower limb, can serve as an additional decision-making aid. In prospective and retrospective studies, MESS values of at least 7 points achieved positive predictive value of 100 % for amputation, also for the upper extremity [24, 42, 75].

Key recommendation:

3.57	**Recommendation**	**2011**
GoR B	**During the primary operative phase, debridement and bony stabilization should be performed.**	

Explanation:
Debridement and stabilization of the bony hand has priority in an open injury, while nerve, tendon, and skin reconstruction can take place at a later time [12, 27, 65, 79, 91]. Time-consuming definitive reconstructions of the soft tissue structures should be undertaken during the secondary operative phase. The benefits and disadvantages (time required, operative trauma, mobilization) of drill wire fixation should be weighed against those of stable plate and screw fixation [14, 15, 27].

Skin and Soft Tissue Injuries Including Burns/Chemical Damage

Explanation:
During primary operative management, debridement of avital and contaminated tissue parts should be performed [15, 78]. Keeping the wound surface and deeper structures moist with appropriate dressing techniques is more important than an attempt at soft tissue coverage during primary operative management [12].
If wounds are clean and free of infection, definitive defect coverage should be undertaken during the secondary phase (5th to 12th day). In this case, the selected procedure should be that offering the best chance of a stable defect reconstruction with the least stress on the patient [33, 59].

Key recommendations:

3.58	**Recommendation**	**2011**
GoR B	**The initial treatment of extensive skin and soft-tissue damage should include thorough debridement followed by moisture-retention measures for areas of the wound that cannot be closed primarily.**	
3.59	**Recommendation**	**2011**
GoR B	**Thermally/chemically damaged, completely avital skin areas should undergo primary debridement.**	
3.60	**Recommendation**	**2011**
GoR B	**In cases of deeper and larger areas of thermal/chemical damage, an escharotomy, similar to a compartment syndrome procedure, should be performed.**	
3.61	Recommendation	**2016 invalid!**
GoR B	For the conservative treatment of superficial burns (Grades 1-2a), sulfadiazine silver cream or synthetic dressing material should be used, and for the temporary management of deeper burns (Grades 2b-3), hydrocolloid or vacuum-sealing dressings are preferable.	

Explanation:

Thermal injuries around the hand require initial debridement and removal of all definitely avital areas. This can be used to make an initial assessment of the depth of injury (grades 1 to 3).

There is debate regarding whether blisters should be removed from superficial dermal lesions (grade 2a) [68, 90]. Proponents of blister retention postulate that the blister fluid creates a favorable wound-healing environment. In addition, pain intensity should be less and processes like cellular proliferation and angiogenesis are supported [64, 71]. In most German-speaking burn treatment centers, the blisters are removed during the initial treatment on admission. The reason is the high concentration of pro-inflammatory cytokines within the blister, which can lead to delayed wound healing. The protein-rich fluid within the blister also offers a fertile breeding ground for bacterial growth [41, 62].

In addition, after extensive initial debridement, circulatory disorders can be better detected and treated appropriately. When there are deep-grade, circular burn lesions around the hands, perfusion problems should be suspected. Immediate fasciotomy should be performed (for the technique, see the section on compartment syndrome).

After completion of the primary operative measures, an antiseptic dressing should be applied. Moist dressings with clear, antiseptic substances (e.g., octenisept, polyhexanide) are preferred.

For clearly superficial dermal lesions (grade 2a), hydrocolloid, PU foam, or membrane dressings can be applied after the initial care measures. When these biosynthetic dressings are used, re-epithelization of the area should occur within two weeks, due to the vital skin integument, among other things. There are other dressing arrangements known to support the regeneration process [39].

However, the decision to place these dressing systems can also be made during the reevaluation at 24 hours post-initial treatment.

Silver sulfadiazine cream should not be used in superficial (grade 2a) and deep dermal (grade 2b) burns. In addition to impaired determination of injury depth, a meta-analysis found worse wound healing outcomes when silver sulfadiazine cream was applied [102].

Definite third-degree areas, in other words, areas that will need recurrent surgical interventions over the course of treatment, can be treated with silver sulfadiazine cream.

Once the initial surgery is completed, it is advisable to elevate the extremity to prevent edema.

Tendon Injuries (Flexor Tendons, Extensor Tendons)

Key recommendation:

3.62	**Recommendation**	**2011**
GoR B	**Time-consuming tendon repair should not be performed primarily.**	

Explanation:

There is debate regarding whether a severed flexor tendon should be managed by primary or delayed primary closure [51, 52, 54, 82-86]. However, time-consuming tendon repairs can be carried out during the secondary phase (5th to 7th day) in multiply-injured patients without evident disadvantages [15, 78-80, 84, 85, 103]. In contrast, the so-called secondary flexor tendon reconstructions (after weeks) are unfavorable [97].

In principle, the same recommendations apply to the timetable for the reconstruction of extensor tendons as for flexor tendons. However, the extent of soft tissue mantle damage and open articular injuries can make primary definitive management necessary [23, 98].

The choice of technique for flexor tendon repair depends on surgeon preference, as individual experience and execution are more important than the choice of suture technique [85].

In cases when both flexor tendons have been severed, reconstruction of both tendons is favored [51, 52, 59, 79, 82-86]. However, some authors prefer reconstruction of the deep tendon alone in zone 2 because of better functional results [20, 47, 54]. In addition, a prospective randomized study found that in zone 2 (Tang's subdivision 2C), particularly in cases of delayed primary repair, it is preferable to resect the superficial tendon and reconstruct the deep tendon alone [92]. Thus, in zone 2 and particularly in cases of delayed primary repair, the deep tendon alone should be reconstructed.

Routine administration of antibiotics is not indicated in delayed primary flexor tendon repair. In a retrospective cohort study, Stone and Davidson [80] reported that not giving antibiotics in primary or delayed primary flexor tendon reconstruction does not increase the risk of infection [80]. In polytrauma patients, antibiotic administration depends more on the presence of other injuries or emergence of infectious complications.

Nerve Injuries of the Hand

Key recommendation:

3.63	**Recommendation**	**2011**
GoR 0	**For presumed closed nerve injuries, complex diagnostic measures or surgical release can be foregone during the primary operative phase.**	

Explanation:
Closed nerve damage to the hand is the result of pressure or traction forces. An interruption in nerve continuity is not expected. Thus, primary operative revision is not indicated. Exceptions to this are nerve lesions secondary to fractures or dislocations, where the nerve can be exposed and decompressed during surgical management of the bony injury. Thus, there is no need to carry out time-consuming diagnostic measures to detect suspected lesions while the patient is still unconscious [15]. The development of clinical symptoms and neurophysiological parameters can be anticipated.

Key recommendation:

3.64	**Recommendation**	**2011**
GoR B	**The operative reconstruction of open nerve injuries should be delayed primary repair.**	

Explanation:
Open nerve injuries require time-consuming microsurgical reconstruction. The best possible outcome must be achieved through the initial nerve reconstruction [21]. Thus, these procedures should be undertaken as delayed primary reconstruction during the secondary phase between the 5th and 7th days [13, 78, 103]. Later secondary reconstruction leads to worse outcomes [7, 48, 49, 58, 96]. It is helpful to identify and atraumatically mark the nerve stumps during the first emergency procedure [15].

Compartment Syndrome

Key recommendation:

3.65	**Recommendation**	**2011**
GoR 0	**A pressure measurement device can be used when compartment syndrome of the hand is clinically suspected.**	

Explanation:
Early diagnosis of compartment syndrome is crucial, since irreversible damage of muscle and nerves results within eight hours [104]. The diagnosis is primarily made based on clinical criteria [44, 45]. Normal coloration and temperature of the fingers and the presence of distal pulses [8, 26, 40, 44, 61, 104] do not exclude compartment syndrome. The cardinal symptoms of pain and pain provoked by muscle extension and sensory tests are generally of no use in unconscious or sedated polytrauma patients. Provided a compartment syndrome has not already been clinically diagnosed, a definitive diagnosis can be established using a pressure measurement device [63, 69]. Compartment pressures over 30 mmHg or, in cases of hypotension, exceeding the difference BP(diastolic) - 30 mmHg, are considered threshold values and are indications for fasciotomy in an unconscious patient [40, 60, 61, 104].

Key recommendation:

3.66	**Recommendation**	**2011**
GoR A	**For manifest compartment syndrome of the hand, fasciotomy must be performed immediately.**	

Explanation:
Once the diagnosis of compartment syndrome has been established, immediate fasciotomy is indicated. Early sufficient dermato-fasciotomy prevents ischemic contractures and is considered an emergency intervention [26, 40, 44, 61, 104].
If compartment syndrome has been detected clinically or using a device, all ten compartments of the hand should be decompressed via four incisions, whereas in the forearm a single palmar fasciotomy is sufficient. In the forearm, palmar fasciotomy is begun as a parathenar carpal tunnel incision and continued to the elbow flexure by dividing the bicipital aponeurosis, for which median arch-shaped and palmar-ulnar incision lines are equally effective [32, 104]. If pressure is not sufficiently lowered in the dorsal compartment, additional decompression via a straight medial incision of the dorsal forearm is necessary [32, 69]. The ten compartments of the hand must be decompressed via several incisions. The dorsal and palmar interosseous compartments can be accessed by dorsal incisions over the 2nd and 4th metacarpals. The thenar and hypothenar compartments are reached through incisions along the radial side of the 1st and the ulnar side of the 5th metacarpals, respectively [69].
The indication for fasciotomy of the fingers is made according to clinical criteria. Because the pressure measurement device is not practical for use in the fingers, the degree of swelling is used to establish an indication for

fasciotomy. The incision is made unilaterally, radially for the thumb and little finger, and ulnar for the remaining fingers. A mid-lateral incision from fingertip to interdigital crease is preferred. The Cleland ligaments should be divided bilaterally within the flexor tendon canal while protecting the neurovascular bundle [69].

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3.10 Lower Extremity

Key recommendations:

3.67	Recommendation	2011
GoR 0	**In adult patients with multiple injuries, isolated and multiple shaft fractures of the long bones of the lower extremity can be treated either with primary definitive or primary temporary and secondary definitive osteosynthesis.**	
3.68	**Recommendation**	**2011**
GoR 0	**As an exception, isolated closed tibial shaft fractures can also undergo primary temporary stabilization in a plaster cast.**	

Explanation:

Regarding isolated long bone shaft fractures of the lower extremities, there are two contradictory treatment strategies: a) primary definitive internal fixation, and b) two-stage fixation with secondary definitive care. Of all published controlled studies examining femoral shaft fractures in polytrauma patients, only a minority have prospective or randomized study designs. The majority of papers were based on retrospective hospital data. Along with the primary objective criterion of mortality, there are numerous secondary outcomes: complication rates (from malunion to sepsis and organ failure), intensive care duration, ventilation parameters, cardiopulmonary changes, and hospital stay. Only a few authors backed up their treatment regimens with prospectively raised laboratory findings. Approximately one third of the investigations favored later treatment of the long bones, while two thirds considered early treatment superior. Other authors were undecided regarding the ideal timeframe. Most of the authors emphasized that there are particular patient groups (chest and/or brain injured patients) in whom one method is particularly (contra)indicated. Specifically, controlled studies on management strategies for isolated tibia fractures in polytrauma were not identified. In summary, early definitive operative stabilization is increasingly favored in the literature; however, the type and timing for this stabilization remain topics of debate. Thus, overall, it is best to take a risk profile-adjusted approach. In this way, the majority of severely injured patients who are hemodynamically stable within 24 hours can be safely treated primarily. Patients with hemodynamic instability, hemorrhagic shock, or a distinct combination of severe individual injuries should be initially managed with an external fixator as part of a damage control strategy. In borderline cases, particularly in patients with concomitant traumatic brain injury or lack of adequate improvement in hemodynamic and respiratory parameters despite extensive, initial ED and intensive care management (quantified by the lack of normalization of lactate levels as well as improved ventilation parameters), the decision to use external fixation as a damage control procedure should be liberal [32, 39].

Management strategies for multiple femoral and lower leg fractures in polytrauma patients have not yet been conclusively investigated. Although the reported incidence of multiple femur and tibia fractures suggests its clinical significance, with 2-7 %, it is rarely discussed in the literature. Most studies rely on retrospective hospital data (n = 42, 4-222 patients) and case reports (n = 29). Along with the primary objective criterion of mortality, there are numerous secondary outcomes such as complication rates, length of stay, and associated injuries. The vast majority of authors see the advantages of early stabilization of fractures; however, debate remains regarding the procedure and the timing. In the only prospective study to date, a high number of pulmonary complications were seen in the group with multiple intramedullary nails (8.2 versus 62.5 %) [209]. As a consequence, the author recommends a staged treatment strategy. In other studies with retrospective data, authors found no increased risk for pulmonary complications such as (fat) pulmonary emboli after multiple intramedullary nails. On the other hand, they found shorter rehabilitation times and lower complication rates in operatively stabilized (pediatric) patients, and advocate primary definitive stabilization. In summary, early definitive operative stabilization is increasingly favored in the literature; however, the type and timing for this stabilization remain topics of debate. Thus, analogous to treatment of isolated injuries of the lower extremities (see above), it is best to take an approach adapted to the risk profile [32, 39, 181]. In this way, the majority of severely injured patients who are hemodynamically stable within 24 hours can then be safely treated primarily with (multiple) intramedullary nails. Patients with hemodynamic instability, hemorrhagic shock, or a distinct combination of severe individual injuries should be initially managed with an external fixator as part of a damage control strategy. In borderline cases, particularly in patients with concomitant traumatic brain injury or lack of adequate improvement in hemodynamic and respiratory parameters despite extensive, initial ED and intensive care management (quantified by the lack of normalization of lactate levels as well as improved ventilation parameters), the decision to use external fixation as a damage control procedure should be liberal.

Since both isolated and multiple long bone fractures of the lower extremities are clinically relevant, routine situations in the management of multiply injured patients, there is a somewhat urgent need for additional prospective studies with an adequate study design to clarify therapy strategies. Regarding risk assessment (damage control) of multiply injured patients, please refer to the introductory chapter of the Primary Operative Management section of this guideline for decision-making help with fracture care strategies.

Key recommendations:

3.69	**Recommendation**	**2011**
GoR 0	**Proximal femoral fractures in multiply injured patients can be stabilized with primary osteosynthesis.**	
3.70	**Recommendation**	**2011**
GoR 0	**In particular cases warranting it, a joint-spanning external fixator can be used.**	

Explanation:

There are no controlled studies evaluating treatment of proximal femur fractures specifically in multiply injured patients. The following cites studies including both monotrauma and polytrauma patients with proximal femur fractures [36, 105, 106]. Proximal femur fractures are classified according to location as intracapsular, extracapsular (trochanteric), and subtrochanteric fractures.

Femoral head fractures (Pipkin fractures) are rare and often associated with hip dislocation and/or acetabular fractures. Operative treatment ranges from the removal of small osteochondral fragments to re-fixation up to femoral head reconstruction. Femoral neck fractures are common among the elderly after relatively trivial trauma; however, in younger patients they are mostly caused by high velocity trauma, often associated with multiple additional injuries. As a femoral head preserving procedure, (cannulated) screw fixation is favored [10, 94, 133, 134, 136, 137]. Prosthetic replacement is reported as equivalent [87, 133, 134, 136, 142, 156, 191]. While the meta-analyses of Bhandari et al. [11] and Parker et al. [135, 138, 139] found much higher revision rates after fixation for isolated femoral neck fractures, the group with joint replacement had increased infection rates, blood loss, operative time, and tendency for mortality [11]. To date, there has been no evidence that a bipolar prosthesis is superior to total joint replacement in polytrauma patients [33, 38, 135, 138, 139].

For extracapsular fractures, treatment can be performed with extramedullary fixed plate sliding screw fixation (dynamic hip screw, Medoff sliding plate, etc.) or intramedullary procedures (proximal femoral nail, gamma nail, etc.) [7, 27, 28, 37, 53, 64, 72, 73, 91, 102-104 [, 124, 132-136, 138, 139, 141, 147, 197]. Generally, surgical management of proximal femur fractures is considered standard treatment [7, 23, 43, 55, 62, 100, 135, 138-140, 202].

There is no evidence from randomized studies regarding the timing of fracture management; and observational studies have reached various conclusions [22, 45, 70, 140, 194]. Early operative management (within 24-36 hours) after physiological stabilization is recommended for most patients. Unnecessary delays of surgery can increase complication rates (decubiti, pneumonia). Urgent indications for surgery include open fractures, fractures with vascular injury, fractures with compartment syndrome. If the operation must be significantly delayed (> 48 hours), a joint-spanning external fixator can be temporarily (or permanently, if necessary) applied. Potential complications are: bleeding, infection, wound healing disturbances, avascular necrosis of the femoral head, malunion, rotational deformity, limited range of motion, prosthetic dislocation, thrombosis, embolism [130].

Regarding risk assessment (damage control) of multiply injured patients, please refer to the introductory chapter of the Primary Operative Management section of this guideline for decision-making help with fracture care strategies.

Key recommendation:

3.71	Recommendation	2011
GoR B	**For definitive treatment of femoral shaft fractures in polytrauma patients, intramedullary locking nail fixation should be the operation of choice.**	

Explanation:

Surgical stabilization of femoral shaft fractures is considered standard treatment (see Key Recommendation 3.71). Urgent indications for surgery include open fractures, fractures with vascular injury, fractures with compartment syndrome. In hemodynamically stable situations (see Emergency Department management), early definitive osteosynthesis is standard, with most authors considering intramedullary nails as the gold standard [26, 31, 97, 201]. The central argument of proponents is the ability for early weight-bearing.

Nevertheless, in a retrospective study of 255 patients with femur fractures, Neudeck et al. [121] reported that only 29 % of these patients, considering injury severity, pattern of injury, and clinical course, were able to benefit from early weight-bearing after primary intramedullary nailing. Thus, the choice of primary operative approach (nailing versus plate fixation) in polytrauma patients remains a matter of debate for a few authors [5, 16, 18, 84, 92, 128, 163, 170, 176]. Bone et al. [16] found that the incidence of pulmonary complications is not dependent on the type of stabilization (nail/plate), but solely on the lung injury. In a retrospective study of 217 patients with reamed femoral nail and 206 patients with plate fixation, Bosse et al. [18] also found no difference in the incidence of respiratory failure (ARDS) in multiply injured patients with and without chest trauma. In a retrospective study of primary plate fixation, Aufmkolk et al. [5] reported no increased mortality and morbidity of patients with and without chest trauma (AIS Thorax $\geq$ 3). In support of this, several animal models, including one by Wozasek et al. [203], found no evidence of a significant pulmonary-hemodynamic effect between medullary nailing and plate osteosynthesis. There is no dispute that fat embolism occurs as a result of increased intramedullary pressure during nailing and has been proven in many animal studies especially with echocardiography [148]. Whether this is clinically relevant remains unclear and thus, also the question of whether un-reamed intramedullary nails should be favored. Correspondingly, several prospective randomized studies comparing reamed and un-reamed medullary nailing found no differences in the ARDS rate, pulmonary complications, or survival [4, 34].

Primary intramedullary nails are considered contraindicated in hemodynamically stable patients with open grade III femur fractures and vascular involvement [52, 121, 184]. In these cases, alternative procedures such as external fixators are applied [168].

Femoral shaft fractures are characterized by good callus formation and low risk of complications [25]. Ten to twenty percent of femoral shaft fractures are associated with ligamentous injuries in the knee joint. Potential complications are: bleeding, infection, wound healing disturbances, avascular necrosis of the femoral head, malunion, rotational deformity, limited range of motion, thrombosis, embolism.

Regarding the timing of surgery, Patel et al. found that the earliest possible definitive osteosynthesis should be standard, and it makes no difference whether or not the patient undergoes surgery within "normal" daytime operating hours, in terms of quality of care [145].

Regarding risk assessment (damage control) of multiply injured patients, please refer to the introductory chapter of the Primary Operative Management section of this guideline for decision-making help with fracture care strategies.

Key recommendation:

3.72	Recommendation	2011
GoR 0	**Unstable distal femoral fractures in polytrauma patients can undergo primary operative stabilization.**	

Explanation:

There are no controlled studies evaluating treatment for distal femur fractures specifically in multiply injured patients. The following cites studies including both monotrauma and polytrauma patients with distal femur fractures. Surgical treatment of distal femur fractures is considered standard management. Urgent indications for surgery include open fractures, fractures with vascular injury, fractures with compartment syndrome. In hemodynamically stable situations, early definitive osteosynthesis is standard. Depending on the fracture type, both intra-articular fractures and fractures with no articular involvement of the distal femur can be treated with open or closed reduction and fixation with plate (less invasive stabilization system [LISS], angled plate, etc.) or retrograde nailing [66, 79, 89, 127, 171, 182, 210]. In hemodynamically unstable situations or within a damage control framework, a joint-spanning external fixator can also be temporarily placed.

Potential complications are: bleeding, infection, wound healing disturbances, malunion, rotational deformity, limited range of motion, thrombosis, embolism, early arthritis.

Primary definitive fixation is considered contraindicated in hemodynamically stable patients with unstable open grade III distal femur fractures. In these cases, alternative procedures such as external fixators are applied [48].

Regarding risk assessment (damage control) of multiply injured patients, please refer to the introductory chapter of the Primary Operative Management section of this guideline for decision-making help with fracture care strategies.

Key recommendations:

3.73	**Recommendation**	**2011**
GoR A	**Knee dislocations must be reduced at the earliest opportunity.**	
3.74	**Recommendation**	**2011**
GoR B	**Knee dislocations should be immobilized at the earliest opportunity.**	

Explanation:

There are no controlled studies evaluating treatment for knee dislocations specifically in multiply injured patients. The following cites studies including both monotrauma and polytrauma patients with knee dislocations. Highest management priority is given to vascular injuries (popliteal artery) that need treatment. The study of 245 knee dislocation patients by Green and Allen [57] reported vascular injuries in 32 % of cases. 86 % of patients undergoing surgery beyond the 8-hour treatment window required amputation, and 2/3rds of the remaining patients retained an ischemic contracture. If ischemia time exceeds the 6-hour window and there is a threatened compartment syndrome, compartment release surgery is recommended.

In hemodynamically stable and unstable polytrauma patients, knee dislocation should be reduced at the earliest possible opportunity. If closed reduction is unsuccessful, the dislocated joint is reduced open [77]. In planned conservative treatment and in planned early cruciate ligament reconstruction, the reduction result can be stabilized with an external fixator and Steinmann nail or with brace/cast. According to expert opinion, external fixators have the advantage over other methods [93]. MR-compatible implants should be used to enable imaging after reduction and temporary fixation.

Ligamentous injuries after knee dislocation can be treated either operatively or conservatively. The meta-analysis of Dedmond and Almekinders [40] evaluated the clinical results from twelve retrospective and three prospective studies of patients after knee dislocation, with 132 treated operatively and 74 treated conservatively. Patients treated operatively had significantly better results regarding range of motion (123° vs. 108°), Lysholm score (85.2 vs. 66.5), and decreased flexion contracture (0.5° vs 3.5°). The groups were not randomized, and the indications for operative or conservative therapy were not given. Two additional retrospective studies have also reported superiority for results of operative versus non-operative therapy [115, 162].

For the surgical treatment of the cruciate ligaments after knee dislocation, either direct repair or ligament replacement are available. In a retrospective study with a small case number, Mariani et al. [107] found that in the context of knee dislocation, stability and range of motion were superior when anterior and posterior cruciate ligament reconstruction with patellar or semitendinosus tendon was performed versus direct repair [107].

Key recommendation:

3.75	**Recommendation**	**2011**
GoR 0	**Unstable proximal tibial fractures and tibial plateau fractures can undergo primary stabilization.**	

Explanation:

There are no controlled studies evaluating treatment for proximal tibia fractures specifically in multiply injured patients. The following cites studies including both monotrauma and polytrauma patients with proximal tibia fractures.

Primary management can be carried out with splint immobilization. Non-displaced fractures are treated conservatively with non-weight-bearing and functional therapy. If needed, operative fixation can be performed to prevent secondary displacement. Surgical treatment of displaced proximal tibia fractures is considered standard care [75, 116]. Competing procedures are plate systems (conventional, fixed angle "less invasive stabilization system" - LISS, etc.), tibial nails, screws, and fixator systems [8, 85, 123, 157] that can be selected based on the complexity and joint surface involvement of the fracture. Requirements for internal fixation are the option for joint surface reconstruction and permanent fracture retention as well as stability during mobilization exercises while minimizing perioperative soft tissue injury. In cases of low-grade displacement, percutaneous screw fixation with arthroscopic and radiological reduction assistance can be performed [60]. Urgent indications for surgery include open fractures, fractures with vascular injury, fractures with compartment syndrome. In these cases, an external fixator can be placed if needed until the soft tissue conditions allow definitive treatment. In hemodynamically stable situations, early definitive elective osteosynthesis once the initial swelling is reduced (e.g., after 3-5 days) is standard. Up to 50 % of tibial plateau fractures have associated meniscus injuries, and up to 25 % have associated ligamentous injuries [9].

Potential complications are [208]: bleeding, infection, wound healing disturbances, malunion, rotational deformity, limited range of motion, thrombosis, embolism, premature arthritis.

Regarding risk assessment (damage control) of multiply injured patients, please refer to the introductory chapter of the Primary Operative Management section of this guideline for decision-making help with fracture care strategies.

Key recommendation:

3.76	Recommendation	2011
GoR B	**Tibial shaft fractures should be operatively stabilized.**	

Explanation:

There are no controlled studies evaluating the optimal treatment for tibial shaft fractures specifically in multiply injured patients. The major requirement is management adapted to overall patient condition. Because of the marginal soft-tissue coverage at the distal half of the tibia, treatment strategies are often not dictated by the fracture itself, but more based on the soft-tissue conditions.

Stable fractures with minimal displacement can be treated conservatively with cast immobilization [167]. Surgical treatment of unstable tibial shaft fractures is considered standard care - generally with intramedullary nailing [163, 200, 204]. Urgent indications for surgery include open fractures, fractures with vascular injury, fractures with compartment syndrome. In hemodynamically stable situations, early definitive osteosynthesis is standard. If the operation must be significantly delayed (> 48 hours) or if there is an extensive open injury with high-grade contamination, an external fixator can also temporarily (or permanently, if necessary) be applied [80].

A meta-analysis by Bhandari et al. [12] evaluated the treatment of open tibial shaft fractures. They reported that un-reamed intramedullary nails reduced the risks of re-operation, malunion, and superficial infection compared to external fixators. Reamed nails showed a slightly smaller risk for re-operation than un-reamed nails. A prospective randomized study also found lower rates of re-operation and malunion after reamed versus un-reamed intramedullary nails [95]. Tibial shaft fractures are associated with ligamentous injuries in up to 22 % of cases. Potential complications are: bleeding, infection, wound healing disturbances, soft tissue necrosis with the need for plastic coverage (flap-plasty), malunion, rotational deformity, limited range of motion, thrombosis, embolism. Regarding risk assessment (damage control) of multiply injured patients, please refer to the introductory chapter of the Primary Operative Management section of this guideline for decision-making help with fracture care strategies.

Key recommendation:

3.77	Recommendation	2011
GoR B	**Distal lower leg fractures including distal tibial articular fractures should be operatively stabilized.**	

Explanation:

There are no controlled studies evaluating treatment for distal tibia fractures specifically in multiply injured patients. The following cites studies including both monotrauma and polytrauma patients with distal tibia fractures.

Surgical treatment of distal tibia fractures is considered standard management. Because of the marginal soft-tissue coverage at the distal half of the tibia (and Pilon), treatment strategies are often not dictated by the fracture itself, but more based on the soft-tissue conditions. Urgent indications for surgery include open fractures, fractures with vascular injury, fractures with compartment syndrome. In hemodynamically stable situations, early definitive osteosynthesis is standard. Distal tibial fractures without Pilon involvement can be treated with intramedullary nailing. Fixed angle plate fixation is an additional option, particularly with plates inserted through a smaller incision. In the case of additional fibular fracture, additional plate fixation of the fibula is recommended (to construct a solid frame and avoid distal axis deviation) [17, 41, 61, 99, 155, 159, 178, 190, 198]. When the Pilon is involved, open reduction and internal fixation are considered standard treatment [25, 68, 187, 205]. If the operation must be significantly delayed (> 48 hours), e.g. in the case of marked swelling or open contamination, a joint-spanning external fixator can be temporarily (or permanently, if necessary) applied, if necessary with percutaneous fixation of the joint surface (screws, K-wires). Potential complications are: bleeding, infection, wound healing disturbances, soft tissue necrosis with the need for plastic coverage (flap-plasty), malunion, rotational deformity, limited range of motion, thrombosis, embolism, premature arthritis. Regarding risk assessment (damage control) of multiply injured patients, please refer to the introductory chapter of the Primary Operative Management section of this guideline for decision-making help with fracture care strategies.

Key recommendation:

3.78	Recommendation	2011
GoR B	**Ankle fractures should undergo primary stabilization.**	

Explanation:

There are no controlled studies evaluating isolated treatment for ankle fractures specifically in multiply injured patients. The following cites studies including both monotrauma and polytrauma patients with ankle fractures. Operative treatment overall and the type of internal fixation for fibula fractures depend on the overall pattern of injury in the patient with multiple injuries. Some authors prefer external fixation when the ISS > 25 or 29 points and/or there is chest trauma of AIS > 3 [120, 3, 167]. In addition, the fracture type determines the choice of fixation materials.

Proximal Fibula: In Maisonneuve injuries, the distal fibula should be operatively fixed to the tibia in the upper ankle [47]. Two syndesmosis screws should be inserted. Because they are tricortical, they offer 5-fold greater tear and rotational strength than syndesmosis suture alone [56, 206].

Fibula Shaft: High fibular fractures such as those after a pronation-eversion injury Lauge Hansen type III or IV should be treated operatively (plate fixation). The complex disruption mechanism may have resulted as well in other bony (medial malleolar) and ligamentous (syndesmosis, medial/lateral capsular ligament) injuries [161].

Distal Fibula: Isolated malleolar fractures must be distinguished as “stable” and “unstable” fractures. Stable fractures are those at the level of the syndesmosis (Weber B1) and supination-eversion fractures SE type II according to Luage Hansen [24, 44, 160, 207]. A lateral malleolar fracture is considered stable when there is no fibular shortening, displacement is not > 2 mm, there is no angular deformity, and the posterior syndesmosis is intact [44, 160]. Stable lateral malleolar fractures can be treated conservatively, e.g. in a plaster cast or a synthetic orthotic. Other fractures must be treated operatively.

The type of internal fixation depends on the accompanying soft-tissue injury (contusion, swelling, compartment syndrome) [150]. In higher grade soft-tissue injuries or complex fracture types (e.g., fracture-dislocations), the initial goal is external fixation regardless of the extent of remaining injuries, to prevent neurovascular damage [21]. In cases of stable lateral malleolar fractures or lateral malleolar fractures that have been operatively stabilized, significant improvements of ankle mobility and shorter rehabilitation times have been achieved with a follow up treatment strategy including early functional therapy and weight-bearing [152].

Regarding risk assessment (damage control) of multiply injured patients, please refer to the introductory chapter of the Primary Operative Management section of this guideline for decision-making help with fracture care strategies.

Key recommendation:

3.79	Recommendation	2011
GoR A	**Perioperative antibiotic prophylaxis must be administered for both open and closed lower extremity fracture surgeries.**	

Explanation:

In open fractures, there is preoperative bacterial contamination in 48-60% of all wounds and in 100% of severe wounds (101].

Antibiotic Administration in Closed Fractures:

During operative management of closed fractures, administration of antibiotic prophylaxis (typically a single dose of a long-acting 1st generation cephalosporin) is generally recommended when implanting a foreign material [78, 149]. For the management of femoral neck fractures, there is evidence level 1 data that perioperative antibiotic therapy yields significantly fewer postoperative wound infections [19, 29, 30, 78]. A 2003 Cochrane review of data from 8307 patients in 22 studies found a significant reduction in post-operative wound infections as well as genitourinary and respiratory infections through the use of single-shot antibiotic administration during surgery for fractures of the long bones of the extremities. Neither the Cochrane review by Gillespie et al. [54] nor the meta-analysis by Slobogean et al. [175] identified benefits of multi-dose over single-shot antibiotic administration.

Antibiotic Administration in Open Fractures:

In cases of open fractures, there is sufficient evidence that antimicrobial prophylaxis should be carried out. The EAST (Eastern Association for the Surgery of Trauma) guidelines recommend that in addition to careful wound debridement, coverage for gram-positive pathogens should be begun as soon as possible [59, 71]. For Gustilo grade III fractures, additional therapy against gram-negative pathogens and high dose penicillin for farm-related injuries should be given as prophylaxis for clostridial infections. Treatment should be continued until 24 hours after coverage of the primary defect. In grade III fractures, antibiotic therapy should be administered for up to 72 hours after trauma and not more than 24 hours after soft-tissue coverage has been performed [101]. Like a series of other studies [67], Dellinger et al. [42] found no significant difference in infection rates depending on the duration of antibiotic prophylaxis (1 vs. 5 days) in 248 patients [81, 188].

The use of antibiotic carriers, such as antibiotic impregnated beads (PMMA), for local prophylaxis in pronounced open injuries with serious contamination has been increasingly favored in the literature to complement systemic intravenous antibiotic treatment [35, 63, 81].

However, the specific indications for this, the type, and the timing of local application remain subjects of debate [67, 69, 126, 172].

Key recommendation:

3.80	Recommendation	2011
GoR B	**Provided the overall injury severity of the patient allows, operative treatment of vascular injuries of the lower extremity should be performed as soon as possible, i.e. directly after treatment of life-threatening injuries.**	

Explanation:
There is very little verified data regarding the incidence of vascular injuries of the lower extremity in multiply injured patients. There is wide variation among worldwide collectives regarding the severity, mechanism of injury, localization of vascular injury (and other injuries), and the quality of preoperative evaluation and management [151, 179, 185, 189, 193]. The morphological damage to the vessels depending on the mechanism of injury is specifically reported regarding its importance for the type of management [195].

Treatment recommendations given here are based primarily on the experience and recommendations of experts who have published their results and conclusions for individual patient collectives. Only one publication was based on a controlled, randomized study [196]. However, the published recommendations from various areas of trauma and vascular surgery enable only limited conclusions regarding the treatment for severe injuries of the lower extremity with vascular involvement in multiply injured patients. Thus, ultimately, an individual decision must be made for each individual patient.

Provided the overall injury severity of the patient allows, operative treatment of vascular injuries of the lower extremity should be performed as soon as possible also in polytrauma patients, i.e. directly after treatment of life-threatening injuries. There is no consensus in the literature whether the greatest advantage is offered by fracture stabilization prior to vascular reconstruction or vice versa. Interim solutions (such as primary shunt placement to stabilize perfusion, fracture stabilization, and later definitive vascular reconstruction, or providing a damage control framework until physiological recompensation after severe trauma) are also under discussion [82, 110, 119, 122, 125, 129, 146, 183]. In cases of complex trauma when there is a high probability of vascular injury, primary vascular revision should be performed, with immediate vascular reconstruction if needed [196]. The resources, operative principles, and operative techniques correspond to those for management of non-trauma-induced arterial and venous reconstructions and sometimes extend beyond the indication spectrum.

Arterial injuries of the iliac and femoral vessel tracts should be reconstructed and are usually technically easily accessible. An isolated crural artery injury can be ligated if there is confirmation that the major distal arteries are patent. When there are injuries affecting at least two vessels, there is almost always a critical perfusion disorder that requires primary revascularization. The combination with venous injuries increases the rate of amputation, which is why venous reconstruction should be widely performed when treating combination injuries [51, 179, 185]. Arterial injuries of the lower extremity should be treated with (in descending order) direct suture, insertion of a continuity-preserving anastomosis, patch angioplasty (autologous, synthetic), or bypass reconstruction (autologous, synthetic, composite) [46, 193]. Venous injuries of the lower extremities should be treated with (in descending order) patch graft, autologous vein interposition graft, PTFE (polytetrafluorethylene) interposition graft, or primary ligature [1, 113, 131, 143, 144, 158, 186].

The indication for fasciotomy should be made early; if necessary, it should be carried out before the vascular reconstruction [50, 179].

Endovascular therapy is another alternative for the treatment of lower extremity arterial injuries even in polytrauma patients. Established procedures (coiling, coated stents) generally applied to the proximal extremity can also be used peripherally in individual cases. Temporary revascularization can also be sought prior to definitive surgical management [108, 118, 153, 169].

Key recommendation:

3.81	Recommendation	2011
GoR A	**In compartment syndrome of the lower extremity, immediate compartment decompression and fixation of a concomitant fracture must be performed.**	

Explanation:
Compartment syndromes associated with fractures of the long bones in the lower extremity, and particularly the tibia, are not uncommon. Because of the destructive consequences occurring with a few hours, they require rapid decompression (fasciotomy) during fracture stabilization. Van den Brand et al. [20] even support prophylactic versus therapeutic fasciotomy. Early diagnosis of compartment syndrome is crucial, since irreversible damage of muscle and nerves results within eight hours [199]. The diagnosis is primarily based on clinical criteria [74]. Normal coloration and temperature of the skin as well as the presence of distal pulses [65, 74, 117, 199] do not rule out compartment syndrome. The cardinal symptoms of pain and

pain provoked by muscle extension and sensory tests are generally of no use in unconscious or sedated polytrauma patients. Therefore, in unconscious patients, Rowland et al. [165] suggest that definitive diagnosis should be made with a pressure-measurement device. Compartment pressures over 30 mmHg or, in cases of hypotension, exceeding the difference BP(diastolic) - 30 mmHg, are considered threshold values and are indications for fasciotomy in an unconscious patient [65, 90, 112, 117, 199]. Once the diagnosis of compartment syndrome is made, immediate fasciotomy (emergency procedure) is indicated [65, 74, 117, 199]. All four muscle compartments of the lower leg should be released. The prognosis depends on the overall injury pattern and has the most favorable prognosis in cases of isolated compartment syndrome without fracture. In cases of concomitant fracture, stable bony fixation should be performed with the fasciotomy. Preferred means of stable fixation is intramedullary nailing [49, 192] over other procedures because it leads to less soft-tissue irritation and avoids the need for pin transfixation of the tissues. A meta-analysis by Bhandari et al. [13] evaluated reamed versus un-reamed nails for the relative risk of compartment syndrome. Although the difference was not significant (relative risk 0.45; 95% CI: 0.13-1.56), the authors concluded that reaming the intramedullary nail appears to decrease the risk for compartment syndrome. Nevertheless, the recommendation to act rapidly is based less on specific studies and more on experience with compartment syndrome in patients with multiple injuries.

Key recommendation:

3.82	**Recommendation**	**2011**
GoR B	**The decision to amputate or to salvage the limb in cases of severe injury of the lower extremity should be made on a case-by-case basis. The local and overall condition of the patient plays a decisive role.**	

Explanation:

Critical injuries of the lower extremities can present a complex problem in the treatment of patients with multiple injuries. Often the critical decision between amputation and limb preservation must be made. The literature has shown that the loss of neurological function is correlated with delayed amputation and increased morbidity and mortality [2]. Early amputation should be considered if there is loss of function and sensation of the foot/extremity. Conversely, when function and sensation of the foot/extremity remain intact, the goal should be preservation [2]. Thus, amputation should be standard for all patients such as those with a type IIIc fracture and completely severed sciatic or tibial nerve. No study has shown benefits for extremity salvage versus amputation when there is significant nerve separation [15, 111, 166].

Vascular integrity increases the probability for limb salvage [164]. Perfusion disorders should be remedied as quickly as possible. Ischemia lasting > 6 hours is correlated with irreversible nerve injury and loss of function [96, 180]. For practical reasons, necrotic (parts of the) extremities should be amputated. Delayed amputation leads to significant increases in sepsis, immobility, number of required operative procedures, mortality, and costs [15, 111, 166].

Many reports have been published regarding the objective criteria to decide between amputation and limb salvage [58, 76, 86, 98]. However, to date none of these studies has been able to define guaranteed prediction instruments for this decision. Scoring systems (e.g. predictive salvage index, mangled extremity severity score MESS, limb salvage score or nerve injury, ischemia, soft-tissue injury, skeletal injury, shock and age of patient NISSSA scoring index) can serve as supplements to clinical assessment. Thus, it is absolutely necessary that an individual decision be made for each patient and each injury. The decision to amputate or to salvage an extremity should never be made purely based on the basis of a protocol or algorithm [14].

In summary, primary and secondary amputation rates for injuries of the lower extremity (without being predictable, e.g. through scoring systems) depend on the number and location of concomitant arterial and venous injuries, injured nerves, overall severity of injuries, and the magnitude of accompanying soft-tissue damage [6, 50, 51, 83, 88, 109, 114, 125, 154, 173, 174, 177, 179, 185, 193].

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3.11 Foot

Often, despite a high level of personnel and material resources devoted to management of patients with multiple injuries, there are residual complaints and restricted function in the foot. Foot injuries are often overlooked or underestimated in multiply injured patients because of more eye-catching or life-threatening injuries, deficient x-ray technique in the emergency situation, highly variable clinical standards in patients receiving analgesia and/or sedation, lack of experience by the examiner in uncommon foot injuries, and communication breakdowns in polytrauma management because of several teams working together [1, 52, 67].

There are remarkably few studies with high grade evidence on the management of foot injuries in polytrauma patients. This is all the more worrisome considering that the presence of foot injuries significantly worsens the prognosis of multiply injured patients [94]. For these reasons, there have been repeated attempts to establish experience-based treatment guidelines for this patient group [20, 57, 67, 87, 88, 101, 102]. In the absence of controlled studies, these form the basis of the following outline. Thus, the goal of this section of the guidelines is to provide support for the timely and adequate treatment of foot injuries, based on the extent of injury in the multiply injured patient.

Emergency Indications

The need for emergency management of open fractures, neurovascular injuries, compartment syndromes, and extreme soft tissue hazard is no different from the emergency indications of all bony injuries [17, 87, 88]. Thus, reference will be made to the corresponding guideline sections.

Topographic peculiarities of the foot result from the risk of avascular necrosis even in closed fracture-dislocations of the talus [16, 29, 41, 88], to a lesser degree the navicular bone [81], as well as in Lisfranc fracture-dislocations and calcaneal fractures, which include increased risk of compartment syndromes [53, 59, 65, 73, 104]. In addition, closed reduction of fracture-dislocations of the talus as well as the Chopart and Lisfranc joints is only possible in exceptional cases. These injuries should be managed immediately once the multiply injured patient has been initially stabilized.

Compartment Syndrome of the Foot

Key recommendations:

3.83	**Recommendation**	**2011**
GoR A	**For a manifest compartment syndrome of the foot, fasciotomy must be performed immediately.**	
3.84	**Recommendation**	**2011**
GoR 0	**If there is clinical suspicion of compartment syndrome of the foot, a pressure measurement device can be used.**	

Explanation:

Calcaneus fractures, Lisfranc fracture-dislocations, and severe crush injuries in general are at particular risk for compartment syndromes [47, 53, 59, 65, 79, 87]. Most authors recommend fasciotomy for measurements above 30 mmHg [22, 55, 58, 59, 98]. Other authors recommend compartment release already at 25 mmHg, in contrast to the lower leg, because blisters develop more rapidly on the foot and the tolerance of the small foot muscles as well as the end branches of the nerves and vessels is less compared to comparable pressure in the lower leg [102, 104].

In a series of eight cases, Manoli et al. [46] established that there should be a higher level of suspicion for concomitant compartment syndromes in the foot when compartment syndromes of the lower leg are present. Multiple injuries were present in 7 of 8 cases. Both dorsomedian and medial fasciotomy (modified Henry approach) enable sufficient decompression of all foot compartments [46, 58]. Also reported are two parallel dorsal incisions as well as a "three-incision decompression" with additional medial or plantar fasciotomies; however, there is no obvious advantage to such an approach [79].

Open Injuries

Soft tissue damage of the foot has a crucial effect on functional outcomes [30, 31, 39, 95] [39]. Aggressive debridement of contaminated and hypoperfused tissue as well as early soft tissue coverage are essential during the treatment of open foot fractures to avoid a prolonged course of infection [14, 17, 31, 42, 85, 86, 105].

Even when there is primary foot vitality, bone, articular cartilage, and tendons are themselves at risk if there is insufficient soft tissue coverage. Synthetic skin products can be used temporarily if secondary skin closure is expected once the swelling has decreased and the soft tissues have consolidated, or when an additional second look procedure is needed due to severe contamination (farm injuries) [33]. Secondary split thickness skin grafts are suitable for superficial defects of non-weight-bearing areas. These require a clean (non-sterile) wound base without exposed bone, cartilage, or tendons. In children, the demands for the wound base are much less [2]. There are still unresolved problems with marginal hyperkeratosis at the borders between graft and local foot skin [13]. In degloving injuries, the superficial layer (approximately 0.3 mm) of hypoperfused and potentially avital abraded skin can be detached with the dermatome and used for coverage of neighboring areas with vital wound base (split thickness skin excision) [100]. In addition, the extent of bleeding when the transplant is lifted is a reliable indication of the borders of viability.

Multilayer defects require local or free-flap transfers [42, 51, 78]. The choice of flap here depends on the defect size and the pattern of blood supply and takes into account the functional-anatomical foot zone divisions and the like with like principle [2, 32, 51]. Due to their limited range of use, local pedicled flaps are suitable for covering smaller lateral, medial, or plantar defects [24]. Free flaps with microvascular anastomosis require an intact point of attachment, and in addition to the technical feasibility, consideration must be given to the types of shoes worn and cosmetic aspects [76]. Preoperative angiography (and phlebography if necessary) should be routinely carried out [42]. More extensive defects on the flat dorsum of the foot do well with free fasciocutaneous flaps, while deep, contaminated defect cavities need to be filled with split-thickness muscle flaps (e.g., latissimus dorsi). The latter are less bulky than myocutaneous flaps [49]. When the main vessels are insufficient, a salvage procedure can be performed with a pedicle-rotated sural flap [7, 14, 45].

Even when there is successful limb preservation, there are often considerable functional deficits, particularly after Pilon, talus, and calcaneus fractures [31, 78, 84]. This is explained partially by arthrogenic and tendogenic fibrosis with corresponding mobility deficits after the longer immobilization required. In grade II and III open lower leg fractures, early defect coverage with free flaps has proven superior to delayed coverage [12, 18, 23].

Experience with the foot is less due to smaller patient numbers. In initial series, patients with larger, contaminated defects in open foot trauma reached good functional outcomes with early flap coverage within 24-120 hours and primary stable bony fixation [14, 56, 93] [62] [54]. However, this procedure is only possible for patients in generally stable condition; for optimal functional results, however, all reconstructive options should be attempted in multiply injured patients as well [68].

As with open fractures in other extremity regions, single shot administration of antibiotic prophylaxis is also recommended in the foot as a supplement to surgical debridement; according to the expected predominantly gram-positive pathogens, first or second generation cephalosporins or another antibiotic with a similar spectrum of action should be used [11, 15, 28, 31, 48, 57, 64].

Complex Trauma of the Foot

Key recommendations:

3.85	**Recommendation**	**2011**
GoR B	**The decision to amputate the foot should be made on a case-by-case basis.**	
3.86	**Recommendation**	**2011**
GoR 0	**Foot replantation in multiply injured patients cannot be generally recommended.**	

Explanation:

The definition of complex foot trauma is based on both the regional extent of the injury over the five anatomical-functional levels of the foot and the extent of soft-tissue damage [101]. Thus, one point is awarded for each injured foot region and one point for the grade of soft-tissue damage according to Tscherne and Oestern [91]; complex foot trauma is defined by a score of five or more points. The absolute score value also enables a prognostic statement [101].

The criteria for amputation when complex foot trauma is present in multiply injured patients are not well defined in relation to overall injury severity. Tscherne [91] recommends primary amputation by a PTS score (Hannover Polytrauma Key [75]) of 3-4, and a case-by-case decision with a PTS of 2. Additional help for the decision is offered by the validated Hannover fracture scale (HFS [92]), MESS (Mangled Extremity Severity Score [36]), NISSSA score (Nerve injury, Ischemia, Soft tissue injury, Skeletal injury, Shock and Age of patient [50]), Predictive Salvage Index (PSI) [34], and Limb Salvage Index (LSI) [77]. In a prospective multicenter study of 601 patients with complex injuries of the lower extremity (Lower Extremity Assessment Project, LEAP), all scores (HFS, MESS, NISSSA, PSI, LSI) achieved high specificity but low to moderate sensitivity [8]. This means that a low score can reliably predict limb preservation, but a higher score is not predictive for amputation. Thus, the authors caution against non-critical application of these scores when deciding in favor of amputation [8]. Also, such scores cannot replace the individual considerations of the overall polytrauma course as well as the specific local pattern of foot injury [103, 104].

In addition to general criteria such as age, concomitant medical problems, and accompanying injuries, the following points regarding the foot are important for the decision to amputate. Large portions of the foot sole, with its unique chambered profile, cannot be replaced by equivalent tissue and loss of these is potentially more serious than defects on the dorsum of the foot. Vascular injuries endanger the viability of distal foot sections and severely impair the recovery of foot function [9, 27, 82, 104]. The loss of the protective sensitivity of the foot sole from a traumatic tibial nerve lesion entails greater potential for late soft-tissue related complications even though sensation can be restored within two years for about half of the cases of blunt tibial nerve injury [10].

Severe comminution of the bony framework and joint destruction that requires primary arthrodesis to support internal fixation will potentially lead to a rigid foot with non-physiological pressure distribution on the foot sole, which has often already been compromised by the trauma itself. Traumatic loss of the talus or its joint surfaces with the necessary tibio-talar, tibio-talo-calcaneal, or pan-talar arthrodeses leads to a rigid foot with considerable functional impairment even when there is unproblematic bone and wound healing [25, 78, 81]. In all of these cases, the indication for amputation should be considered early even if there are no life-threatening concomitant injuries [27, 57, 78, 83]. In these cases, the Pirogoff amputation enables the original sole of the foot to bear weight; it is also suitable in cases of critical perfusion conditions [101].

In the LEAP Study at eight North American Level I trauma centers, the most important criteria for amputation in severe high-energy injuries of the lower leg and foot were: severe muscular injury (OR 8.74), severe venous injury (OR 5.72), lack of plantar sensation (OR 5.26), open foot fracture (OR 3.12), and absent foot pulses (OR 2.02). Patient-related factors that influenced the decision in favor of amputation were hemorrhagic shock and concomitant diseases; in this series, the overall injury severity (ISS) had no significant influence [88]. In the LEAP study subgroup analysis of 174 severe open foot injuries, there were significantly worse SIP values after limb preservation versus lower leg amputation when flap coverage and/or ankle arthrodesis were necessary [21]. In an analysis of 50 complex foot injuries, Kinner et al. (2011) reported a significant correlation between amputation and ISS > 16 as well as the primary soft tissue damage [39].

In contrast to the vascular surgery principle of waiting for demarcation of hypoperfused limb areas, in acute trauma, an early decision regarding the need for eventual amputation is advisable to enable early definitive soft-tissue closure [101, 102]. In principle, tourniquets should be avoided during surgery so that the viability of bones and musculature can be accurately assessed [57, 74].

Experience with replantation at the foot is disproportionately less than that at the hand and are limited to case reports and small case series [4, 6, 19, 38, 99] [61]. The outlook for successful replantation is markedly higher in children than in adults [5, 35]. Essentially, the attempt should only be undertaken when a plantigrade, stable foot with intact sole sensation is a realistic endpoint to be achieved from surgery, without endangering the patient. Important criteria for successful replantation are ischemia time of less than 6 hours and high patient compliance with the prospect of slow, difficult rehabilitation [19]. It is almost impossible to estimate this criterion in multiply injured patients, and a replantation that lasts several hours within the critical ischemia period is generally not indicated due to the overall condition of the patient [82].

Specific Injuries

Key recommendation:

3.87	Recommendation	2011
GoR B	**Dislocations and fracture dislocations of the tarsal and metatarsal bones should be reduced and stabilized as soon as possible.**	

Explanation:

Central fracture-dislocations of the talus (“aviator’s astragalus”) are associated with polytrauma with above-average frequency (in 52 % of cases according to the AO multicenter study [41]). The relationship between talar avascular necrosis and the initial extent of dislocation has been demonstrated in several large clinical series [16, 29, 41, 97]. In fracture-dislocations of the talus, closed reduction is rarely possible, and repeated attempts damage the already-compromised soft tissues. For this reason, immediate open reduction and (generally minimally invasive) fixation should be the goal in cases of talar fracture-dislocation (assuming the polytrauma patient’s general condition allows), to avoid further compromise to the vitality of the skin and talus itself [16, 29, 72, 89].In stable patients, definitive care as well as osteosynthesis of mildly displaced talar fractures can be performed after a delay without an increased risk of developing talar avascular necrosis [43, 63, 95, 96].

Calcaneus fractures with open wounds, manifest compartment syndrome, or incarcerated soft tissues should undergo emergency surgery. In open injuries, once diagnostic studies have been performed, the procedure should include initial wound debridement with synthetic skin coverage if needed, temporary percutaneous K-wire fixation or medial transfixation (with one Schanz screw each in the distal tibia, the calcaneus, and the first metatarsal) in order to prevent soft-tissue retraction [31, 74, 103]. Insertion of PMMA (polymethylmethacrylate) beads is recommended in cases of extensive bony defects. A second look operation must generally be carried out within 48-72 hours. The decision for early flap coverage should be made liberally [14, 56].

In patients with multiple injuries and closed grade III fractures with manifest compartment syndrome, emergency dermatofasciotomy is performed over an extensive dorsomedian approach with insertion of a triangular medial external fixator [74, 103]. Although the plantar calcaneal compartment has been characterized in injection studies, and isolated pressure increases have been measured within it, its clinical relevance has not yet been definitively clarified. The occurrence of hammer toe deformities after isolated calcaneus fractures, however, indicate that this problem exists [47, 65, 105].

In the vast majority of fractures (closed soft tissue injuries grades I and II), definitive fixation is recommended after an interval of 6-10 days once soft tissue swelling has subsided [3, 66, 78, 80, 103, 107]. To avoid ischemia, elevating the extremity more than 10 cm over the level of the heart is not recommended [17]. A good indicator that it is time to operate is the onset of skin creasing from the subsidence of edematous swelling [78]. Surgery beyond the 14th day is associated with increased risk of complications if there has been no initial reduction and transfixation [66, 90]. Local contraindications to fixation are critical soft tissue conditions with high risk of infection such as tension blisters and skin necrosis as well as advanced arterial or venous perfusion disturbances; general contraindications are lack of compliance as well as manifest immunodeficiency [66, 101, 103]. Conservative treatment is indicated in these cases because of the risk of wound healing disorders and/or deep infections.

Injuries of the Chopart and Lisfranc joints occur at an above average frequency (50-80 %) in multiply injured patients [40, 73, 106]. They are some of the most commonly overlooked injuries overall, particularly in polytrauma patients [26, 40, 44, 69, 101].

Closed reduction of Chopart and Lisfranc fracture-dislocations is generally not possible; thus, in most cases, there is an indication for emergency surgery [44, 60]. Lisfranc fracture-dislocations are associated with increased risk of foot compartment syndromes [59, 73, 79]. If the patient's overall condition is not compatible with a definitive fixation procedure, Kirschner wire transfixation and/or the application of a tibio-metatarsal external fixator should be attempted; definitive treatment should be delayed [37, 69, 71, 74, 102].

Metatarsal and toe fractures can be managed with internal fixation according to general fixation principles, performed after a delay to stabilize the polytrauma patient's general condition; in open fractures, the general principles listed above apply [70].

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3.12 Mandible and Midface

Securing the Airway, Bleeding

Key recommendation:

3.88	Recommendation	2011
GoR A	**In mandibular and maxillofacial injuries, primary airway protection and hemostasis in the oral and maxillofacial area must be carried out.**	

Explanation:

Immediate securing of the airways and management of profuse bleeding are essential to life [44]. There is often risk of suffocation from foreign bodies (e.g., dental prostheses, tooth and bone fragments, blood clots, mucus, vomit). This risk should be eliminated by manually clearing the oral cavity and the pharynx as well as suctioning the deeper airways [2]. An unstable mandible as a result of comminution or dispersal of the middle fragment can cause the tongue to fall back and displace the airway. This dangerous situation can be remedied through reduction and stabilization of the mandible with wire ligatures attached to available teeth [2]. If the airways in the head and neck area are obstructed by heavy bleeding, tongue swelling, and displacement, then depending on the urgency and feasibility, intubation, tracheotomy, or crichothyroidotomy (coniotomy) are necessary [3, 28].

If the larger vessels are involved (generally the origin of the external carotid artery), surgical hemostasis is necessary. Open surgical hemostasis with vascular ligation, bipolar electrocoagulation, or embolization through angiography is recommended [16, 18, 28]. The exact source of bleeding should be localized for effective hemostasis [38]. Epistaxis is one of the most common types of bleeding. Most bleeding can be stopped through primary compression with tamponade placement [26, 40]. When there is persistent nasopharyngeal bleeding, it is necessary to place Bellocq packing or a balloon catheter [15]. When there is bleeding in the maxillofacial area, particularly from the maxillary artery, an attempt can be made to arrest the bleeding by compressing the maxilla dorsocranially against the base of the skull (e.g., spatula head bandage, dental impression tray with extra-oral brace) [2]. In the case of sagittal maxillary fractures, compression might be necessary, e.g. by a transverse wire suture from the molars on one side to those on the contralateral side [2, 37]. Reduction and fixation of craniofacial fractures are often the best causal therapy even for severe hemorrhages [15].

Facial Soft Tissue Injuries

Key recommendation:

3.89	**Recommendation**	**2011**
GoR B	**Soft-tissue injuries should be managed during the primary operative phase.**	

Explanation:

Soft tissue injuries of the face are either isolated in the form of abrasions, gashes, cuts, contusions, and defect wounds, or in severe trauma, in combination with craniofacial fractures.

Gashes and contusions are the most common soft-tissue injuries [43]. Soft tissue injuries, especially those e.g. with exposed cartilage and/or bone surfaces, should be treated as soon as possible. Ideally this can occur already in the Emergency Department [20]. Among other things, rapid management achieves better aesthetic and functional results [5, 17, 27, 31, 41, 45].

The most important principles in the first hours after trauma are adequate hemostasis and cerebral decompression when there is increased intracranial pressure [24]. Craniofacial and soft tissue injuries are treated as secondary concerns [42]. When there are combined soft tissue injuries with craniofacial fractures, definitive soft tissue care should be carried out after bony reconstruction if possible ("from inside to outside") [22]. Functional structures such as eyelids, lips, the facial nerve, and parotid duct should be reconstructed during primary wound management [39]. Gently cleansing of the wound and removal of foreign bodies are to be performed prior to plastic reconstruction to enable good aesthetic and functional results [21]. Larger reconstructive measures or microvascular reconstructions are generally undertaken in two stages [32].

Tooth Injuries, Alveolar Process Fractures

Key recommendation:

3.90	**Recommendation**	**2011**
GoR B	**The goal for tooth-alveolar process trauma is immediate or if necessary rapid management.**	

Explanation:

The treatment goal for tooth injuries and alveolar process fractures is the restoration of form and function (aesthetics, occlusion, articulation, phonation). Attempts will be made to salvage both tooth and alveolar process structure.

Treatment depends on the vitality and overall suitability for tooth preservation [1].

The prognosis for long-term tooth preservation after avulsion depends on the duration and the storage of the tooth (e.g. in cell culture medium/Dentosafe, cold milk, physiologic saline solution, oral cavity) until successful replantation [9, 10]. The most favorable replantation results are achieved within the first 30 minutes [46]. The most unfavorable prognosis is for avulsed teeth that have been preserved in dry condition for several hours, although there have been individual reports of successful replantations in such cases. For this reason, a replantation attempt can be justified in individual cases even after a longer interval [13].

Treatment for alveolar process fractures should also be initiated as soon as possible [6, 46].

Acute treatment should be carried out within a few hours for cases of extrusion, lateral dislocation, or avulsion of a tooth, alveolar process fracture, or root fracture [1, 6]. Careful handling of the periodontal ligament and rapid fixation with splints or supportive bandaging protect against infections and permanent tooth loss [9, 10, 48].
Management of complicated crown fractures after 3 hours and uncomplicated crown fractures with exposed dentin after 48 hours worsen the prognosis of vital teeth [6].

Mandible and Midface

Key recommendation:

3.91	**Recommendation**	**2011**
GoR 0	**Depending on overall injury severity, treatment of maxillofacial and mandibular fractures can be done during the primary operative phase or as a secondary procedure.**	

Explanation:

The goal of therapy is to restore form and function. Particular value is placed on the restoration of occlusion, articulation, joint function, and aesthetics, as well as the function of motor and/or sensory nerves. Treatment strategy, operative technique, and procedure are comparable in isolated and combination injuries of the mandible and/or midface.
Ideally, early definitive primary treatment of maxillofacial and mandible fractures can be performed [7, 36]. In maxillofacial fractures, early treatment with anatomical reduction and fixation minimizes the development of edema and enables better re-contouring of the facial soft tissues [12, 23, 34]. However, the timing of the procedure is very vaguely reported, with "immediately" or "within the first few days." Bos et al. [4] recommend surgical treatment of maxillofacial fractures with open reduction and internal fixation within 48-72 hours to achieve good aesthetic and functional results and to avoid the need for secondary corrections. In children with maxillofacial fractures, better reduction of the bony fragments and more rapid healing and thus, also better aesthetic results were observed when surgery was performed within a week of trauma [19].
Regarding concomitant traumatic brain injury (TBI), the Glasgow Coma Scale (GCS) gives valuable information regarding the prognosis of the injured patient. However, this does not mean that patients with low GCS must be automatically excluded from the management of craniofacial fractures. Manson [23] reported that patients with head injuries can undergo surgery without increased complication rates, provided that intracranial pressure is kept below 25 mmHg during the procedure. In a retrospective study of 49 patients with mandibular and/or maxillofacial fractures and concomitant traumatic brain injury, Derdyn et al. [8] observed that patients with intracranial pressure below 15 mmHg after early surgical management (0-3 days after trauma) had comparable survival rates to patients undergoing medium-term (4-7 days after trauma) and later ($>$ 7 days) procedures. Postoperative complications were comparable between the patient cohorts undergoing early, medium-term, and late surgery. In contrast, craniofacially-injured patients with low GCS, intracranial bleeding, and shifts in median brain structures after lateral and multisystem trauma had significantly worse prognoses.
Due to improvements in functional and aesthetic outcomes through the use of mini- and microplates and through less invasive surgical techniques [14], there is increasing debate regarding early management within 24-72 hours.
If higher priority is given to the overall condition or other injuries, then definitive management of craniofacial injuries can be postponed to 7-10 days after trauma, with primary management limited to soft tissue injuries and temporary stabilization (e.g., with splint bandaging, wire ligatures, splints) of fractures [7]. Ideally, soft-tissue injury care and temporary stabilization can be performed in the Emergency Department [20].
In a retrospective study of comparable groups with a total of 82 multiply injured patients with mandibular and/or maxillofacial fractures, Weider et al. [47] found that delayed management ($\geq$ 48 hours) did not extend intensive care or hospital admission times. The infection rate was negligible and the complication rate comparable to patients undergoing surgery within 48 hours. Schettler [35] reported no disadvantages when definitive management of maxillofacial fractures occurred within 14 days. Neither infections nor residual eye motility disorders were increased compared to immediate treatment. On the other hand, once the initially severe edema subsided, the complicated reduction of even the smallest bone fragments was much easier to perform. He considers the time between the 5th and 10th day post-trauma as the most favorable period to perform definitive management. Kühne et al. [20] retrospectively analyzed 78 trauma patients with mandibular and/or maxillofacial fractures who underwent surgery. There was a practically identical rate of postoperative complications in the patients treated with early primary (within 72 hours) or delayed (after 72 hours) surgery. The group of patients undergoing delayed surgery had markedly higher overall injury severity than those undergoing early primary management.
Exceptions for delayed management are incessant bleeding from fractures requiring immediate reduction and internal fixation as well as intraorbital or intracranial injuries of the optic nerve requiring therapeutic intervention within a few hours [7]. Retrobulbar hematomas, elevated eye pressure, or direct optic nerve compression with visual impairment can require immediate administration of a cortisone

megadose over 48 hours (30 mg Urbason/kg BW i.v. as bolus, and 5.4 mg Urbason/kg BW hourly over the following 47 hours) and/or immediate surgical decompression of the optic nerve [7, 11, 30, 46].

In injuries involving multiple specialties, the appropriate specialist disciplines must be involved in treatment planning as well as treatment itself [25]. Depending on injury severity, the sequence of measures to be undertaken should be established on an interdisciplinary basis [20, 25, 47].

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3.13 Neck

Key recommendations:

3.92	**Recommendation**	**2011**
GoR A	**Provided that intubation or tracheotomy has not yet been performed, clinical findings relating to the airways must be observed and evaluated prior to anesthetic induction for intubation.**	
3.93	**Recommendation**	**2011**
GoR A	**Intubation tools and a crichothyrotomy (coniotomy) set must be kept available for immediate use. A "difficult airway" algorithm must be adhered to.**	
3.94	**Recommendation**	**2011**
GoR A	**A previously performed crichothyrotomy must be closed operatively. When necessary, tracheotomy must be performed.**	
3.95	**Recommendation**	**2011**
GoR B	**Penetrating trauma to the esophagus should undergo primary reconstruction within 24 hours.**	

Explanation:

When the upper airways are involved in a polytrauma situation, difficulties with intubation are to be expected from swelling, displacement, and/or secretions and blood.

In cases of tracheal tears or avulsion or open tracheal injuries, surgical exploration is recommended with tracheostomy placement or direct reconstruction [1]. The same applies to trauma of the laryngeal region.

Conservative treatment of tracheal tears is a topic of debate. Conservative therapy can be considered for non-gaping, short segment lesions that can be bridged by the endotracheal tube [3]. The majority of studies argue in favor of surgical reconstruction at the earliest opportunity via trans-cervical, thoracotomy, or as an exception, trans-cervical/trans-tracheal approach. Resorbable materials and single interrupted sutures are recommended [1, 2, 4-7]. The decision for tracheotomy in the conventional sense, i.e. epithelialized tracheostomy, versus puncture tracheotomy must be made on a case-by-case basis. On the one hand, there are considerations of the exclusion criteria for puncture tracheotomy, and on the other hand, the risks of iatrogenic damage to neighboring structures [5]. Ease of cannula replacement is a major argument for epithelialized tracheostomy. In cases of laryngeal trauma, early reconstruction should be attempted. There are no references focusing purely on conservative treatment of laryngeal trauma [1, 2, 4-7], especially not considering the prevention of stenosis and vocal disorders. In addition to the removal of stenoses and coverage of cartilage defects, the insertion of indwelling laryngeal stents for several weeks is recommended to prevent stenoses and strictures [2, 4, 5].

Elective tracheotomy should be considered if prolonged mechanical ventilation is expected. Historical studies have reported irreversible damage to the laryngeal and tracheal cartilage even after only 48 hours of orotracheal intubation, for which blood pressure, tube material, and the use of vasoactive substances are important influencing factors. The most critical area is the cricoid cartilage; using modern cuffs (low pressure, high volume), the risk for tracheal stenosis can be lowered with simultaneous cuff pressure monitoring. Early tracheotomy thus serves primarily to prevent cricoid cartilage stenosis.

Damage to the recurrent laryngeal or the vagus nerves can be most easily detected using laryngoscopy (direct and indirect) or stroboscope to evaluate vocal cord mobility. There is no evidence in the literature regarding emergency surgical treatment for suspected recurrent paresis in multiply injured patients. Here, the focus is on confirming airway stenosis possibly caused by post-traumatic vocal cord paralysis. No studies are available examining traumatically induced laryngeal paralysis. The conclusions are based on post-operative paresis after thyroid goiter surgery.

In these cases, conflicting results have been reported with surgical decompression and reconstruction. Noticeable improvements in the patient's situation cannot be derived from available studies. As supplements to endoscopic functional assessments (laryngoscopy/stroboscopy), imaging procedures such as computed tomography can provide evidence regarding localization of the damage [9, 10].

As an alternative to surgery, conservative therapy with antibiotic coverage can be considered for circumscribed perforations in the cervical region of the esophagus [11]. According to case series, the best prognosis for the clinical course is offered by direct repair of all layers within the first 24 hours [12, 13]. The literature states that intrathoracic esophageal injuries should always undergo surgical treatment; there are no studies supporting conservative therapy. In cases where esophageal perforation cannot be directly repaired, partial resections, with interposition grafts if necessary, are recommended [12–18]; alternatively, endoluminal glue application with fibrin adhesive can be considered. It should be noted that none of these recommendations stem from clinical studies, rather from case series and individual reports.

The procedure should be surgical reconstruction, if necessary with arterial vessel interposition grafts. Various non-lumen-occluding injuries can also be treated conservatively (e.g., dissections). Venous reconstruction must not be performed/is not indicated.

Angiography, computed tomography, and duplex/Doppler ultrasound are the investigations of choice for injuries to the neck vessels [21]; this applies unconditionally to Roon and Christensen zones I and III [23]. In zone II, additional surgical exploration is recommended. Although this remains a subject of debate in the literature, it is undisputed that this procedure enables detection and therapy for 100 % of defects [21, 23]. The largest clinically controlled study was performed by Weaver et al. [24] and concluded that reconstruction of the arterial vessels offers the best outcome in penetrating injuries. Reconstruction of arterial vessels must be performed within a timeframe of 120 minutes [20]. However, injuries that don't occlude the lumen can be successfully treated conservatively with monitoring by duplex ultrasound [24].

In cases of pseudoaneurysm or fistulas, neuroradiological endovascular therapy is an alternative to surgical intervention [19]. There are no studies supporting the reconstruction of venous injuries [22].

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3.14 Thermal Skin Injuries and Burns

Foreword:

Epidemiological data show that additional burn injuries are present in approximately 1-2 % of all patients with multiple injuries. Conversely, approximately 5 % of all severely burned patients have concomitant injuries of the head, chest, abdomen, or skeletal system. In addition to explosion injuries, one common mechanism of injury is entrapment within a burning motor vehicle after an accident.

There is no evidence-based literature on combination injuries "polytrauma + burns" and there is very little data regarding the concomitant injuries of severe burns (> 20 % body surface area) in multiply injured patients.

An additional burn injury approximately doubles mortality in polytrauma patients.

Pre-hospital management does not change when burns are present along with multiple injuries, since a burn itself seldom has relevant effects on vital signs. Therefore, the presence of burns does not significantly alter treatment priorities.

In cases of severe burns, burned areas are not treated with local cooling. On the contrary, severely injured patients are especially prone to rapid cooling, which should be prevented if possible, since it affects patient prognosis. The common view of cooling with tap water does influence pain intensity in smaller burns. It does not prevent heat penetration into the tissues.

Severely injured patients with burns should be transported to the closest trauma center. When there is equal accessibility, a trauma center specializing in burn injuries is preferable. In the Emergency Department as well, initial management is no different than that for typical polytrauma patients. In cases of circumferential burns of the chest, respiratory mechanics must be checked and if necessary, decompression escharotomy performed. Similarly, for circumferential burns of the extremities, the need for escharotomy must be evaluated.

Once the vital signs are stabilized and the necessary primary operative management performed, the severely burned patient must be transferred to a burn center associated with a national trauma center.

Key recommendation:

3.96	Recommendation	New 2016
GPP	**When burns are present in addition to other injuries in a severely injured patient, pre-hospital treatment priorities remain the same.**	

Explanation:

Pre-hospital management does not change when burns are present along with multiple injuries, since a burn itself seldom has relevant effects on vital signs. Therefore, the presence of burns does not significantly alter treatment priorities [1, 7].

Key recommendation:

3.97	Recommendation	New 2016
GPP	**In severely injured patients, burn injuries should not be cooled.**	

Explanation:

In cases of severe burns, burned areas are not treated with local cooling. On the contrary, severely injured patients are especially prone to rapid cooling, which should be prevented if possible, since it affects patient prognosis [8]. The common view of cooling with tap water does influence pain intensity in smaller burns. It probably does not prevent heat penetration into the tissues [3].

Special protection against body cooling should be implemented with warm infusions, warming blankets, and electric heaters [8].

Key recommendation:

3.98	Recommendation	New 2016
GPP	**Severely injured patients with burns should be transported to the closest trauma center. When there is equal accessibility, a trauma center specializing in burn injuries is preferable.**	

Explanation:

Maximal interdisciplinary cooperation between the Trauma Team/Trauma Leader and the Burn Surgeon should begin in the Emergency Department. The specialist Burn Surgeon is present in the Emergency Department [2].

Key recommendation:

3.99	Recommendation	New 2016
GPP	**When burns are present in addition to other injuries in a severely injured patient, emergency department treatment priorities remain the same.**	

Explanation:

The burn surgeon participates in the secondary survey and cooperates in the treatment plan/therapy concept as part of the priority assessment [5, 6].

Key recommendation:

3.100	Recommendation	New 2016
GPP	**In cases of burns to the torso affecting respiratory mechanics, escharotomy must be performed immediately.**	

Explanation:

In cases of deep and extensive burns to the skin of the chest, emergency escharotomy must be considered to prevent mechanical impairment of respiration. The decision for this is made by an experienced burn surgeon. In contrast to compartment syndrome, the swelling here is not in the musculature, but in the subcutaneous tissues. Thus, incision of the burn scab (eschar) is sufficient for release. The muscle fascia must not necessarily be opened [4].

The same holds for circumferential burns of the abdominal skin with increased intra-abdominal pressure.

Key recommendation:

3.101	Recommendation	New 2016
GPP	**For burns of the extremities affecting perfusion, rapid escharotomy must be performed.**	

Explanation:

In cases of deep and extensive burns of the extremities, emergency escharotomy must be considered to secure circulation. The decision for this is made by an experienced burn surgeon. In contrast to compartment syndrome, the swelling here is not in the musculature, but in the subcutaneous tissues. Thus, incision of the burn scab (eschar) is sufficient for release. The muscle fascia must not necessarily be opened.

One area of concern is escharotomy of the hands. Here it is especially important to take care that functional structures are not injured. Thus, escharotomy of the thumb must not be performed on the ulnar side, and on the index finger not on the radial side, and the ulnar side of the hand overall must be spared [4].

In principle, the area of patient care in the emergency department should be equipped so that these types of surgical procedures can be performed there.

Key recommendation:

3.102	Recommendation	New 2016
GPP	**Once the vital signs are stabilized and the necessary primary operative management performed, the severely burned patient must be transferred to a burn center associated with a national trauma center.**	

Explanation:

Direct ground-based transport from the trauma scene to a burn injury center is generally possible only over short distances. Most are coordinated through the Central Facility for the Provision of Hospital Beds for Severely Burned Patients (ZA-Schwerbrandverletzte) of Germany. This has been carried out since 1999 by the Rescue Coordination Center Hamburg (24 hours/7 days). All involved centers report changes of occupancy and/or available hospital bed capacity. The nearest suitable available facility can be named per telephone request. The arrangements for transfer are then made autonomously by the participating doctors or hospitals.

Currently in Germany, there are 120 designated burn injury beds for adults and 45 beds for children in 38 centers. Only Berlin keeps 12 beds overall for adults or children under one roof.

Contact:

Telephone Number of the *Central Facility for the Provision of Hospital Beds for Severely Burned Patients* (Hamburg Fire Department):

040/42851-3998

http://www.verbrennungsmedizin.de

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Acknowledgements Polytrauma Guideline Update Group: Bertil Bouillon, Dawid Pieper, Sascha Flohé, Michaela Eikermann, Peggy Prengel, Steffen Ruchholtz, Klaus M. Stürmer, Christian Waydhas, Heiko Trentzsch, Sven Lendemans, Stefan Huber-Wagner, Dieter Rixen, Frank Hildebrand, Christoph Mosch, Ulrike Nienaber, Stefan Sauerland, Martin Schenkel, Maren Walgenbach, Monika Becker, Stefanie Bühn, Simone Heß, Thomas Jaschinski, Tim Mathes, Michael Bernhard, Bernd W. Böttiger, Thomas Bürger, Matthias Fischer, Ralf Gutwald, Markus Hohenfellner, Ernst Klar, Eckhard Rickels, Jürgen Schüttler, Andreas Seekamp, Lothar Swoboda, Thomas J. Vogl, Frank Waldfahrer, Margot Wüstner-Hofmann, Werner

Bader, Andreas Düran, Birgit Gathof, Lucas Geyer, David Häske, Matthias Helm, Peter Hilbert-Carius, Karl-Georg Kanz, Ulrich Kneser, Marcus Lehnhardt, Heiko Lier, Carsten Lott, Corinna Ludwig, Ingo Marzi, Uwe Max Mauer, Jürgen Schäfer, Robert Schwab, Frank Siemers, Erwin Strasser, Lucas Wessel, Stefan Wirth, Thomas Wurmb.