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A Clinical Decision Rule to Predict Adult Patients with Traumatic Intracranial Hemorrhage Who Do Not Require Intensive Care Unit Admission

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Abstract

Objective—To derive a clinical decision rule to identify adult emergency department (ED) patients with traumatic intracranial hemorrhage (tICH) who are at low risk for requiring critical care resources during hospitalization.

Methods—This is a retrospective cohort study of patients (≥18 years) with tICH presenting to the ED. The need for intensive care unit (ICU) admission was defined as the presence of a critical care intervention including: intubation, neurosurgical intervention, blood product transfusion, vasopressor or inotrope administration, invasive monitoring for hemodynamic instability, emergent treatment for arrhythmia, therapeutic angiography, and cardiopulmonary resuscitation. The decision rule was derived using binary recursive partitioning.

Results—A total of 432 patients were identified (median age 48 years) of which 174 patients (40%) had a critical care intervention. We performed binary recursive partitioning with Classification and Regression Trees (CART) software to develop the clinical decision rule. Patients with a normal mental status (Glasgow Coma Score=15), isolated head injury, and age < 65 were considered low risk for a critical care intervention. The derived rule had a sensitivity of 98% (95% confidence interval [CI] 94–99), a specificity of 50% (95% CI 44–56), a positive predictive value of 57% (95% CI 51–62), and a negative predictive value of 97% (95% CI 93–99). The area under the curve for the decision rule was 0.74 (95% CI 0.70–0.77).

Conclusions—This clinical decision rule identifies low risk adult ED patients with tICH who do not need ICU admission. Further validation and refinement of these findings would allow for more appropriate ICU resource utilization.

Keywords

traumatic brain injury; intensive care; clinical decision rule

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Introduction

The rising cost of medical care is a critical issue facing medicine today, particularly intensive care medicine which accounts for one-third of acute hospital charges.[1] Appropriate utilization of intensive care unit (ICU) resources is important to provide safe and efficient health care. ICU admission decisions are highly variable and subjective, often leading to inappropriate admissions to both the ICU and hospital ward. Patients mis-triaged to a non-ICU setting, who then decompensate and require in-hospital transfer to the ICU, have an increased mortality.[2–6] Patients initially admitted to the ICU but never requiring critical care resources are a poor utilization of health care resources. These inappropriate admissions lead to ICU and emergency department (ED) overcrowding, prolonged ED boarding times, and adverse patient outcomes.[7, 8]

Patients with traumatic intracranial hemorrhage (tICH) are often admitted to the ICU for early detection of secondary brain injury from cerebral edema, increased intracranial pressure, and cerebral ischemia.[9] These secondary insults are the leading cause of inpatient death following tICH.[10] The majority of patients with tICH, however, rarely develop hemorrhage progression or need acute neurosurgical intervention.[11, 12] While guidelines suggest the need for in-patient observation for repeated neurological evaluations in patients with tICH, there are no clear recommendations identifying appropriate ICU admission.[13–16] Moreover, admission criteria to ICUs vary widely and significant variability in the management of patients with tICH exists.[17, 18]

The objective of this study is to derive a clinical decision rule to predict the need for ICU admission in adult ED patients with tICH. We hypothesize that a clinical decision rule which identifies a group of patients with tICH, safely managed in a non-ICU setting can be created.

Materials and Methods

Study Design

This is a single center, retrospective cohort study of adult trauma patients who sustained a tICH on initial ED cranial computed tomography (CT) scan and were evaluated at a Level 1 trauma center from May 2006 through December 2008. The institutional review board at the study site approved the study.

Study Setting and Population

We searched the hospital trauma registry for International Statistical Classification of Diseases and Related Health Problems (ninth edition) (ICD-9) codes specific for tICH (codes 851–854) to identify the cohort of subjects. Eligible subjects included adult patients (18 years of age or older) who were identified with an acute tICH on cranial CT during ED evaluation. An acute tICH was defined as the presence of an acute subarachnoid hemorrhage, epidural hematoma, subdural hematoma, intraventricular hemorrhage, intraparenchymal hemorrhage/contusion, or diffuse axonal injury as interpreted by attending radiologist on cranial CT scan. We excluded patients with documented pre-existing "Do-Not-Resuscitate" (DNR) orders. At the study site, patients with tICH are routinely admitted under the trauma or neurological surgical service to the ICU for neurologic monitoring for a minimum of 24 hours following injury.

Study Protocol

Eligible patients underwent data abstraction following previously published guidelines on retrospective chart review.[19] We abstracted data from the electronic medical record using a standardized data collection form with pre-defined variables by a single data abstractor trained to the methodology of data collection (DKN). The data abstractor was not blinded to study hypothesis. Variables collected included age, gender, mechanism of injury, prior anticoagulant use, co-morbidities, initial ED Glasgow Coma Scale (GCS), loss of consciousness, initial ED systolic blood pressure, heart rate, and respiratory rate, and alcohol intoxication. ED radiologic and laboratory variables collected included initial cranial CT results, initial platelet count, international normalized ratio (INR) level, and hematocrit. Additional variables collected during ED and hospital treatment include administration of packed red blood cells (PRBC), fresh frozen plasma (FFP), or recombinant activated factor VII (rFVIIa). ICU and hospital length of stay (days) were also recorded. Alcohol intoxication was considered positive if laboratory ethanol level ≥ 10 mg/dL. Cranial CT results were coded into anatomical categorical variables based on attending radiologist text report. ED data were abstracted prior to knowledge of patient outcomes. Data missing from the medical record were coded as missing in the dataset.

An Abbreviated Injury Score (AIS) for head and neck, face, chest, abdomen, extremities, and external body regions and the overall Injury Severity Score (ISS) were previously available from the trauma registry.[20] These calculations were previously imputed into the trauma registry by data abstractors trained in these calculations. The AIS and ISS are scoring systems developed to measure injury severity based on anatomical injuries divided by body regions.[20] A Marshall Score was calculated based on the initial cranial CT scan results following previously described methodology.[21, 22] It is a validated classification system that predicts patient outcome based on cranial CT findings (Table 1).[21, 22]

Measurements

The primary outcome measure of this study is the presence of a critical care intervention at any point during ED care or hospitalization. The need for ICU admission was defined as the presence of a critical care intervention at any point during ED or hospitalization. The list of definitions of critical care interventions was adapted from the Task Force of American College of Critical Care Medicine Guidelines for ICU admission [23] and represented specific interventions or patient conditions that would warrant intensive care monitoring or management. Definitions of critical care interventions are included in Table 2.

Predictor variables for analysis were determined a priori and were based on clinical sensibility and prior literature.[24–29] These variables included: age, loss of consciousness, mechanism of injury, GCS score, prior anticoagulant medication use, isolated head injury (defined as non-head AIS < 3), initial systolic blood pressure, and Marshall score.

Data Analysis

Data was entered into a spreadsheet and analyzed using STATA 10.0 statistical software (STATA Corp, College Station, TX). Interval data were reported as the median and interquartile range (IQRs). Proportions were presented with 95% confidence intervals. Clinically sensible cutoff values of predictor variables were determined a priori.

We derived the decision rule with binary recursive partitioning using Classification and Regression Trees (CART) software (Salford Systems, San Diego, CA).[30] We used the Ginni splitting function in CART and set the misclassification cost for missing a patient with a critical care intervention at 20:1. This represents the relative cost of misclassifying 20 patients who did not receive a critical care intervention for 1 patient who did receive a critical care intervention. We internally validated the rule using 10-fold internal cross validation.

We required 10 subjects with the outcome of interest for each variable entered into the multivariate model, and planned to evaluate eight different clinical variables.[31] Thus, we required 80 patients with the outcome of interest. Based on preliminary data, we estimated that 20% of eligible patients would receive a critical care intervention, requiring a cohort of 400 patients.

Results

A total of 432 subjects were identified from the trauma registry and met inclusion criteria. Median age was 48 years old (IQR 30–63) and 299 patients (69%; 95%CI 65–74) were male. The majority of patients were admitted to the ICU (407/432; 96%) with the remaining patients admitted to a non-ICU (floor) setting. None were discharged from the ED. The median GCS was 14 (IQR 11–15) with the majority of patients having a GCS 13–15 (71%; 95%CI 66–75). The most common tICHs were intraparenchymal hemorrhage (55%) and subarachnoid hemorrhage (46%). See Table 3 for complete patient characteristics.

One hundred and seventy-four of 432 (40%; 95%CI 36–45) patients had a critical care intervention with mechanical ventilation (32%) and RBC transfusion (16%) the most common types of critical care interventions (Table 4). Differences in predictor variables frequencies between patients with and without a critical care intervention are presented in Table 5.

Binary recursive partitioning derived a rule with the following three predictor variables for requiring a critical care intervention: Abnormal mental status (GCS < 15), non-isolated head injury, and age ≥ 65 years of age (Figure). the generated rule had the following test characteristics: sensitivity = 170/174 (98%; 95%CI 94–99), specificity = 128/258 (50%; 95%CI 44–56), positive predictive value = 170/300 (57%; 95%CI 51–62), and negative predictive value = 128/132 (97%; 95%CI 93–99). The area under the curve for the decision rule was 0.74 (95%CI 0.70–0.77). Internal validation using 10-fold cross validation demonstrated a stable rule.

Four patients were misclassified by the rule (determined to be low risk but had a critical care intervention) (Table 6). Two patients received a critical care intervention due to head injury; one patient requiring endotracheal intubation for neurological deterioration during ED evaluation and another patient underwent craniotomy for an epidural hematoma. One patient received FFP transfusions for a pre-existing coagulopathy and another patient underwent endotracheal intubation on hospital day three for delirium tremens. All patients survived to hospital discharge.

Discussion

The primary objective of this study was to derive a clinical decision rule to identify a subset of low risk patients with tICH who do not need to be admitted to the ICU. Using binary recursive partitioning, we were able to develop a decision rule with excellent test characteristics. The results are promising for a number of reasons. First, the rule is highly sensitive in detecting a large number of patients with the outcome of interest (sensitivity 98%). Second, the high risk variables identified by the rule makes clinical sense as being predictive of requiring critical care interventions in patients with tICH. These variables previously have demonstrated to be prognostic in tICH.[24–28] Third, a significant proportion of patients with tICH (31%) were low risk by the clinical decision rule. This suggests that successful validation and implementation of this rule will have a broad impact with significant resource sparing.[32]

Prior studies have evaluated baseline characteristics to predict outcome in traumatic patients with tICH.[33–35] Trauma scoring systems including the ISS [36] and the Revised Trauma Score (RTS)[37] predict mortality and other functional outcomes[28] but are not designed as an ICU triage tool as they are calculated after the patient is discharged. A number of other prediction models specific to traumatic brain injury (TBI) exist, however the methodology is limited, and they are not clinically practical.[28] Only one study to date attempts to predict the need for specialized ICU admission in patients with tICH evaluating baseline characteristics.[34] Age and pupillary reactivity were significant predictors however the authors were unable to develop a sufficiently accurate prediction model. This study, however, did not evaluate patients with mild tICH (GCS scores 13–15) and had a high threshold for requiring ICU admission (raised intracranial pressure and need for neurosurgical intervention). Compared to these prior trauma scoring systems and prediction models, our decision rule is largely generalizable to all patients with tICH in the ED and uses data readily available to clinicians.

The decision rule failed to identify four patients who ultimately underwent a critical care intervention which may be concerning to some clinicians. Closer inspection of these cases, however, indicates that the failure of the clinical decision rule to identify these patients would likely have little impact on the patients' outcomes. One patient underwent endotracheal intubation in the ED for declining mental status after returning from CT scanning. A second patient was taken from the ED for neurosurgery for a large epidural. Thus, both these interventions occurred prior to disposition from the ED. The other two patients' interventions were unrelated to their tICH. Thus, the clinical decision rule's rule performance was perhaps better than reported.

The list of critical care interventions was adapted from prior published guidelines that broadly defined disease and physiological conditions that warranted ICU admission.[23] This list was narrowed to represent critical care interventions specific for the injured patient. While most critical care interventions are universally equated to requiring ICU admission (i.e.: mechanical ventilation, neurosurgical intervention, invasive monitoring) certain interventions (specifically RBC and FFP transfusion) may be considered by clinicians to not require ICU admission. We opted to include blood product transfusion in our primary analysis since our aim was to provide clinicians with the most conservative model. Analysis without blood product transfusion derived the same model with similar test characteristics: sensitivity = 140/143 98%; 95% CI 94–100), specificity = 129/289 (45%; 95%CI 39–51), and AUC = 0.71 (95%CI 0.68–0.74).

Our study has several limitations. This study is retrospective and is subject to the limitations of medical record review. This study was conducted at a single, Level 1 trauma center where severity of injury, hospital resources, and management of TBI might not be generalizable to other settings. At the study site, the large majority of patients were admitted to the ICU and thus we are unable to appropriately evaluate patients with tICH that were managed in a non-ICU setting. Moreover, unexpected advantages with ICU care in these patients that prevented a critical care intervention from occurring would not be identified. For example, tICH patients admitted to the ICU at our center have neurological checks by nursing staff every one hour compared to every two hours or greater in non-ICU settings. Finally, the use of other multivariate analysis methodology may have produced a more accurate rule. We did conduct multivariate logistical regression which identified abnormal mental status (GCS < 15), non-isolated head injury, and Marshall score > 2 as predictive of a critical care intervention. Absence of any of these high risk criteria derived a rule that was less sensitive (93%; 95%CI 88–96) than the rule derived by binary recursive partitioning. This is consistent with other studies which demonstrate that logistic regression tends to derive a rule that has a higher overall accuracy (i.e.: better overall classification of patients) while binary recursive partitioning tends to have a higher overall sensitivity (though dependent on assigned misclassification costs).[32, 38]

Despite the promising results of this preliminary study, clinical decision rules are best derived and validated on prospectively collected data.[32] Thus, these results require confirmation and potential refinement in a prospective study. First, clinical data is more reliable when collected prospectively. This is particularly true for the measurement of the outcome of interest (critical care interventions) which relies on accurate medical record documentation. Moreover prospective data has less missing data compared to retrospective data.[32] Second, the predictor variable of isolated head injury was defined as non-head AIS < 3. AIS and ISS are generally not determined until the hospital course is completed, although calculation of this score may be done once the cranial CT scan results are obtained, during the patient's ED evaluation. Thus, this predictor variable may have limited use by clinicians at the time the admission decision is being determined. Prospectively collected data allows a specifically defined isolated head injury definition based on actual injuries. Third, we were unable to collect data on physician gestalt in the retrospective study. Demonstrating that the clinical decision rule performs better than physician gestalt is important for successful implementation of the rule.[32] Fourth, validation should be conducted on a separate dataset using the clinical decision rule.[32] This would mitigate potential bias from evaluation of the same dataset. Finally, the retrospective data was obtained from a trauma registry which may not have captured all eligible patients making it prone to selection bias.

Conclusion

In conclusion, we were able to derive a clinical decision rule which accurately identifies a low risk subset of patients with tICH that do not require ICU admission. Further validation and refinement of these findings would allow for more appropriate ICU resource utilization.

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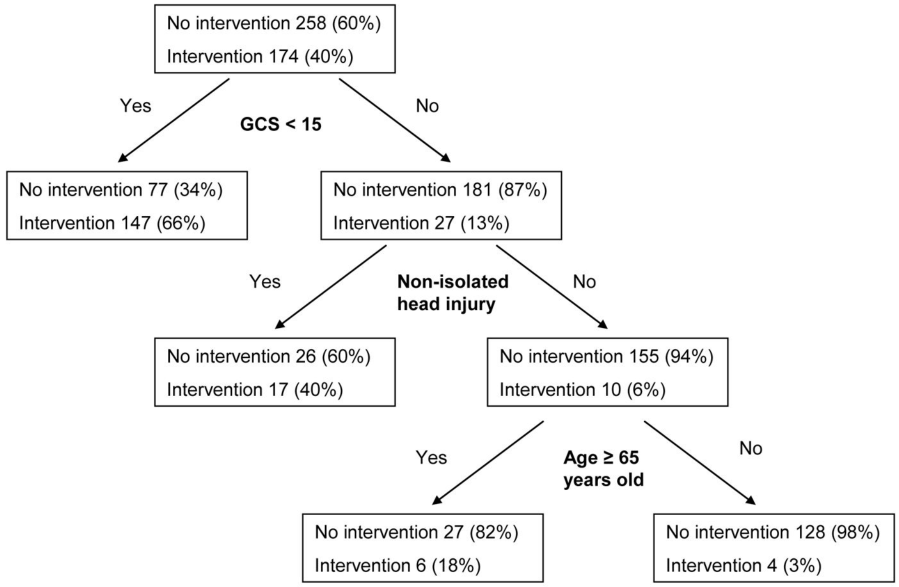

Figure.
Derived model from binary recursive partitioning

Table 1

Marshall score

Class	Definition
CT Class 1	No lesions present
CT Class 2	Lesions and/or midline shift ≤ 5 mm, cisterns present; no high- or mixed-density lesions > 25 cm^3
CT Class 3	Midline shift ≤ 5 mm, cisterns compressed or absent, no high- or mixed-density lesions > 25 cm^3
CT Class 4	Midline shift > 5 mm, no high- or mixed-density lesions > 25 cm^3
CT Class 5	Any surgically evacuated lesion
CT Class 6	High- or mixed-density lesions > 25 cm^3 not surgically evacuated

Table 2

Definitions of critical care interventions

Critical care intervention	**Definition**
Mechanical ventilation	Mechanical ventilation for acute respiratory failure
RBC transfusion	Transfusion of packed red blood cells
FFP transfusion	Transfusion of fresh frozen plasma
Neurosurgical intervention	Craniotomy/craniectomy, burr hole evaluation of hematoma, placement of a subdural drain, placement of an intracranial pressure monitor/intraventricular catheter, or treatment with mannitol or hypertonic saline
Invasive monitoring	Use of central venous catheter to measure central venous pressure (not for venous access alone), or the use an arterial line to measure blood pressure, or the use of a pulmonary artery catheter to measure pulmonary artery wedge pressure
Arrhythmia	Non-sinus arrhythmia less than 40 or greater than 120 beats/minute with the need for urgent intervention
Vasopressor or inotrope use	Use of dopamine, norepinephrine, epinephrine, dobutamine, phenylephrine, or vasopressin for vasopressor or inotropic support
Interventional angiography	Use of interventional angiography for therapeutic purposes
Cardiac arrest	Cardiac arrest requiring cardiopulmonary resuscitation

Table 3

Patient characteristics

Characteristic	**Patients**	**% or Median (95% CI or IQR)**
History of anticoagulant use	34/432	7.9% (95%CI 5.5–11)
Fall from standing	103/432	24% (95%CI 20–28)
Fall from height	31/432	7.2% (95%CI 4.9–10)
Motor vehicle collision	170/432	39% (95%CI 35–44)
Pedestrian struck	29/432	6.7% (95%CI 4.5–9.5)
Bicyclist struck	18/432	4.2% (95%CI 2.5–6.5)
Gunshot wound	7/432	1.6% (95%CI 0.65–3.3)
Direct blow	61/432	14% (95%CI 11–18)
Unknown mechanism of injury	13/432	3.0% (95%CI 1.6–5.1)
Alcohol intoxication	137/430	32% (95%CI 27–36)
Initial systolic blood pressure (mmHg)	-	134 (IQR 119–150)
Initial heart rate	-	90 (IQR 70–102)
Initial respiratory rate	-	18 (IQR 16–20)
Initial platelet count (per ml)	-	232 (IQR 192–287)
Initial INR	-	1.0 (IQR 0.95–1.1)
Initial hematocrit (%)	-	40 (IQR 35–43)
Injury severity		
Mild TBI: GCS 13–15	306/432	71% (95%CI 66–75)
Moderate TBI: GCS 9–12	31/432	7.2% (95%CI 4.9–10)
Severe TBI: GCS < 8	95/432	22% (95%CI 18–26)
Isolated head injury	321/432	74% (95%CI 70–78)
Loss of consciousness reported	175/421	42% (95%CI 37–46)
Abbreviated injury score, head	-	4 (IQR 3–4)
Injury severity score	-	17 (IQR 16–25)
Marshall Score	-	2 (IQR 2-2)
Cranial CT scan injuries		
Depressed skull fracture	4/432	0.9% (95%CI 0.02–2.4)
Nondepressed skull fracture	30/432	6.9% (95%CI 4.7–9.8)
Intraparenchymal hemorrhage	238/432	55% (95%CI 50–60)
Subdural hemorrhage	160/432	37% (95%CI 32–42)
Epidural hemorrhage	19/432	4.4% (95%CI 2.7–6.8)
Subarachnoid hemorrhage	199/432	46% (95%CI 41–51)
Interventricular hemorrhage	41/432	9.5% (95%CI 6.9–13)
Diffuse axonal injury	15/432	3.5% (95%CI 2.0–5.7)
Presence of cerebral shift	44/432	10% (95%CI 7.5–13)
Presence of cerebral mass effect	53/432	12% (95%CI 9.3–16)
Herniation	24/432	5.6% (95%CI 3.6–8.2)

Abbreviations: GCS, Glasgow Coma Score; TBI, traumatic brain injury; CT, computed tomography; INR, international normalized ratio; IQR, Interquartile range; CI, confidence interval

Table 4

Critical care interventions

Critical care intervention*	**Patients**	**% (95% CI)**
Mechanical ventilation	137/432	32% (95%CI 27–36)
RBC transfusion	68/432	16% (95%CI 12–20)
FFP transfusion	44/432	10% (95%CI 7.5–13)
Neurosurgical intervention	31/432	7.2% (95%CI 4.9–10)
Invasive monitoring	6/432	1.4% (95%CI 0.51–3.0)
Arrhythmias requiring treatment	4/432	0.93% (95%CI 0.25–2.4)
Vasopressor or inotrope use	3/432	0.69% (95%CI 0.14–0.20)
Interventional angiography	1/432	0.23% (95%CI 0–1.3)
Cardiac arrest	0/432	0% (95%CI 0–0.85)

Abbreviations: RBC, red blood cell; FFP, fresh frozen plasma; CI, confidence interval

*see table 1 for definitions of critical care intervention

Table 5

Bivariate analysis of tree predictor variables of critical care intervention

Variable	Critical care intervention n=174 (%; 95% CI)	No critical care intervention n=258 (%, 95% CI)	Difference in proportions (95% CI)
Abnormal mental status	147 (84%; 95%CI 78–90)	77 (30%; 95%CI 24–36)	54% (95%CI 45–60)
Marshall score > 2	59 (34%; 95%CI 27–41)	10 (3.9%; 95%CI 1.9–7.0)	30% (95%CI 27–41)
Non-isolated head injury	75 (43%; 95%CI 36–51)	36 (14%; 95%CI 10–19)	29% (95%CI 21–38)
Non-fall from standing	138 (79%; 95%CI 73–85)	189 (73%; 95%CI 67–79)	6.1% (95%CI −2.0–14)
Initial SBP < 90 mmHg	10 (5.7%; 95%CI 2.8–10)	2 (0.78%; 95%CI 0.09–2.8)	5.0% (95%CI 1.4–8.6)
Age ≥ 65 years	44 (25%; 95%CI 19–32)	53 (21%; 95%CI 16–26)	4.8% (95%CI −3.4–13)
Loss of consciousness *	71 (42%; 95%CI 34–50)	104 (41%; 95%CI 35–48)	0.3% (95%CI −9.3–10)
Anti-coagulant use	12 (6.9%; 95%CI 3.6–12)	22 (8.5%; 95%CI 5.4–13)	−1.6% (95%CI −6.7–3.4)

Abbreviations: SBP, systolic blood pressure; CI, confidence interval

* Variable missing in 4 subjects with critical care intervention and 7 subjects without critical care intervention

Table 6

Patients misclassified as low risk by the clinical decision rule

Patient	Critical care intervention	LOS (ICU, hospital)
62 year old male in MVC	Intubated on hospital day # 3 for delirium tremens	13, 27
55 year old male with a ground level fall	Intubated in the ED after declining mental status upon return from computed tomography scan	6, 17
21 year old male in MVC two days prior to ED arrival	Maintained normal mental status but taken for craniotomy due to size of epidural hematoma	2, 7
41 year old male with a ground level fall and a history of end stage liver disease	Initial INR was 1.84 thus required 2 units of fresh frozen plasma in ED, no other blood product transfusion during hospitalization	5, 59

Abbreviations: MVC, motor vehicle collision; ED, emergency department; INR, international normalized ratio; LOS, length of stay; ICU, intensive care unit; GCS, Glasgow Coma Score; ISS, injury severity score