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Caring for the Future: Global Characteristics of the Blast Injured Child

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5 ***Caring for the Future: Global Characteristics of the Blast Injured Child***
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Confidential: For Review Only

Key questions

What is already known about this topic?

- Approximately one in six children live in conflict zones, where exposure to blast injuries is not uncommon.
- Blast injuries have the potential to inflict significant mortality and morbidity upon the global paediatric population living in conflict zones.
- Describing the characteristics of injuries sustained by the paediatric population is essential in advancing local and global health policies.
- Despite this, common themes related to paediatric injury following to blasts are poorly described.

What are the new findings?

- The demographics, mortality and injuries that are specific characteristics of blast injuries upon the paediatric population are described.
- Children are uniquely vulnerable to different injury patterns following blast injuries compared to adults.
- Treatment service requirement for the paediatric population is significant and disproportionate compared to cohort size, and provisions for increased operative and bed requirement is essential.

Recommendations for policy

- These results highlight and quantify the scope of the paediatric injury burden posed by blasts.
- These results highlight priorities in caring for the paediatric population, and where future service provision can be optimised.

Abstract

Background and significance. Blast injuries arising from high explosive weaponry is common in conflict areas. While blast injury characteristics are well recognised in the adults, there is a lack of consensus as to whether these characteristics translate to the paediatric population. Understanding blast injury patterns in this cohort is essential for providing appropriate provision of services and care for this vulnerable cohort.

Methods. In this mixed-method review, original papers were screened for data pertaining to paediatric injuries following blasts. Information on demographics, morbidity and mortality and service requirements were evaluated.

Results. Children affected by blast injuries are predominantly male and their injuries arise from explosive remnants of war, particularly unexploded ordnance. Blasts show increased morbidity and mortality in younger children, while older children have injury patterns similar to adults. Head and burn injuries represent a significant cause of mortality in young children, while lower limb morbidity is reduced compared to adults. Children have a disproportionate requirement for both operative and non-operative service resources, and provisions for this burden are essential.

Conclusions. Certain characteristics of paediatric injuries arising from blasts are distinct from that of the adult cohort, while the intensive demands on services highlights the importance of understanding the diverse injury patterns in order to optimise future service provisions in caring for this vulnerable cohort.

1. Introduction

Approximately one in six children live in conflict zones, with the main global burden borne by citizens of low and middle income countries (LMICs)(1). Children enmeshed in conflict and post-conflict zones are frequently exposed to high-order explosives (HE), either through explosive remnants of war (ERW) such as landmines and unexploded ordinance (UXOs), military ordinance such as shelling and aerial bombardments or acts perpetrated by non-state actors such as improvised explosive devices (IEDs) and suicide bombing(2). HE can inflict unique and unusual injuries upon the child through the blast over-pressure wave (primary blast injury), energisation of materials causing fragmentation (secondary blast injury), bodily displacement or crush injuries (tertiary blast injuries) and through burns, inhalation, toxic or psychological trauma (quaternary blast injuries)(3).

Article 3.3 of the UN Convention on the Rights of the Child (UNCRC) states that medical care of the child be delivered and supervised by providers competent in that field(4). However, paediatric care in conflict zones is often delivered by personnel for whom experience of dealing with paediatric blast injuries is unusual(5). Primary studies increasingly recognise the complex patterns of injury sustained in the adult population following blast exposure(3), however there is a lack of consensus as to whether applying lessons learnt from the adult population translates appropriately into paediatric cohorts(6). Bree et al(7) argue that principles for life-saving interventions, such as prioritising catastrophic haemorrhage, airway, breathing and circulation are just as applicable in children as adults. Conversely Fendya et al(8) contend that directly applying adult trauma principles to the paediatric population neglects the social, anatomical, physiological and psychological differences between adults and children, affecting the validity of these inferences.

While primary studies have described injuries sustained by the blast injured child, no study has attempted to synthesise the data to identify recurrent characteristics in this vulnerable cohort. Understanding the characteristics of such injuries to the paediatric population will advance efforts to prevent, mitigate, and treat these injuries in domestic and deployed health systems(3). The aim of this review is to provide an overview of injury patterns and challenges in caring for the blast-injured child, in order to define future research needs for protection, mitigation, immediate medical treatment, and rehabilitation.

2. Methods

In this mixed-methods review, original peer-reviewed quantitative, qualitative and mixed-method observational studies, in addition to grey literature, were screened for data on

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3 explosive injuries in paediatric cohorts. By utilising all study designs, greater capture of
4 relevant literature was achieved, although this meant the data was unsuitable for a formal
5 systematic review. PubMed and Scopus (including Embase) were searched. Search terms
6 including “Paediatric” OR “Pediatric” OR “Child*” OR “Children” AND “Blast” OR “Explosi*” OR
7 “Explosion” were used to capture potential studies. Articles had to be written in English and
8 published before December 16, 2018. Studies involving adult as well as children were
9 included, in addition to articles where the mechanism of injury was mixed. This decision was
10 taken in order to accurately reflect the settings the studies represent, where victims in conflict
11 zones are heterogenous and subject to a variety of combat related mechanisms. Studies were
12 omitted if they did not specify explosive mechanisms or include children.
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20 Children are defined as all humans under the age of eighteen years (as specified by the United
21 Nations Convention on the Rights of the Child)(4). The heterogeneity and arbitrary nature of
22 what defines a child is acknowledged, and studies often utilise individual definitions. Within
23 this review ages are defined thus: <1 year are infants, 1-8 are young children; 9-13 are older
24 children and 14-18 are adolescents.
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3. Results

47,580 eligible studies were found following academic database searches, of which 4,433 were removed as duplicates, leaving 43,147 of papers for title assessment. 906 (2.1%) of these papers had their abstracts assessed, of which 242 (0.6%) studies were included for full text review. Data were extracted from 74 (0.2%) studies for use within this review (Table 1).

Table 1. The 74 studies included within the review

	Monitoring period	Location	Setting	Sample Size	Population	Exposure	Study	Effect investigated
Aharonson-Daniel et al (2003)(9)	2000-2001	Israel	Civilian	138	Paediatric (100%)	IEDs/Suicide IEDs (67%) GSW (25%) Other (8%)	Retrospective. National Trauma Registry	Injuries and Mortality
Aharonson-Daniel et al (2006)(10)	2000-2004	Israel	Civilian	1155	Paediatric (8%) Adult (92%)	Suicide IEDs (100%)	Retrospective. National Trauma Registry	Injuries and mortality
Al-Worikat et al (2001)(11)	1988-2000	Jordan	Civilian	226	Paediatric (10%) Adult (90%)	Landmines (100%)	Retrospective. Hospital based case series	Long term sequelae
Amir et al (2005)(12)	2000-2002	Israel	Civilian	148	Paediatric (100%)	IEDs/Shelling (66%) GSW (34%)	Retrospective. National Trauma Registry	Injuries and mortality
Andersson et al (1995)(13)	1994-1995	Afghanistan Bosnia Cambodia Mozambique	Civilian	2100	Paediatric (100%)	Landmines (100%)	Retrospective. community surveillance	Socio-economic
Arafat et al (2017)(14)	2012-2013	Syria	Civilian	324	Paediatric (18%) Adult (82%)	IEDs/Shelling (57%) GSW (43%)	Retrospective. Multi-centre Hospital based case series	Injuries and mortality
Arul et al (2012)(15)	2011	Afghanistan	Military	82	Paediatric (100%)	IEDs/Shelling (52%) GSW (11%) Non-combat (37%)	Retrospective. Single centre Hospital based case series	Injuries and mortality
Bajec et al (1993)(16)	1991	Kuwait	Civilian	152	Paediatric (12%) Adult (88%)	Landmines (100%)	Retrospective. Single centre Hospital based case series	Injuries and mortality
Beitler et al (2006)(17)	2002	Afghanistan	Military	204	Paediatric (28%) Adult (72%)	Non-combat (44%) IEDs/Shelling (36%) GSW (20%)	Retrospective. Single centre Hospital based case series	Injuries and mortality
Bendinelli et al (2009)(18)	2003-2006	Cambodia	Civilian	356	Paediatric (26%) Adult (74%)	Landmines (67%) UXO (33%)	Retrospective. Multi centre Hospital based case series	Injuries and mortality
Bertani et al (2015)(19)	2009-2013	Afghanistan	Military	89	Paediatric (100%)	IEDs/Shelling (79%) GSW (21%)	Retrospective. Single centre Hospital based case series	Injuries and mortality
Bilukha et al (2003)(20)	2001-2002	Afghanistan	Civilian	1636	Paediatric (46%) Adult (54%)	UXO (47%) Landmine (41%) Other/Unknown (12%)	Retrospective. Community Surveillance	Injuries and mortality
Bilukha et al (2007)(21)	1994-2005	Chechnya	Civilian	3021	Paediatric (30%) Adult (70%)	Landmines (41%) UXO (37%) Other/Unknown (22%)	Retrospective. Community Surveillance	Injuries and mortality
Bilukha et al (2008)(22)	2002-2006	Afghanistan	Civilian	5471	Paediatric (54%) Adult (46%)	UXO (50%) Landmines (42%) Other/Unknown (8%)	Retrospective. Community Surveillance	Injuries and mortality
Bilukha et al (2011)(23)	2006-2010	Nepal	Civilian	307	Paediatric (58%) Adult (42%)	IEDs (76%) Landmines (4%) Other/Unknown (20%)	Retrospective. Community Surveillance	Injuries and mortality
Bilukha et al (2013)(24)	2008-2011	Nepal	Civilian	437	Paediatric (14%) Adult (76%)	IEDs (69%) Other/Unknown (31%)	Retrospective. Community Surveillance	Injuries and mortality
Bilukha et al (2015)(25)	2010-2013	Iraq	Civilian	2803	Paediatric (13%) Adult (87%)	IEDs (49%) Other/Unknown (51%)	Retrospective. Military Trauma Registry	Injuries and mortality
Bitterman et al (2016)(26)	2013	Israel	Military	84	Paediatric (100%)	IEDs/Shelling (67%) GSW (23%) Non-Combat (10%)	Retrospective. Military Trauma Registry	Injuries and mortality
Borgman et al (2012)(27)	2001-2011	Afghanistan Iraq	Military	128582	Paediatric (6%) Adult (94%)	Non-Combat (40%) IEDs/Shelling (38%) GSW (22%)	Retrospective. Military Trauma Registry	Injuries and mortality
Borgman et al (2015)(28)	2003-2011	Afghanistan Iraq	Military	549	Paediatric (100%)	Non-Combat (84%) IEDs/Shelling (11%) Other/Unknown (5%)	Retrospective. Military Trauma Registry	Injuries and mortality
Borgman et al (2018)(29)	2002-2009	Afghanistan Iraq	Military	707	Paediatric (100%)	IEDs/Shelling (44%) Other/Unknown (56%)	Retrospective. Military Trauma Registry	Injuries and Mortality
Coppola et al (2006)(30)	2004-2005	Iraq	Military	85	Paediatric (100%)	IEDs/Shelling (29%) Non-combat (44%) Other/Unknown (27%)	Retrospective. Single centre Hospital based case series	Injuries and Mortality
Can et al (2009)(31)	2001-2008	Turkey	Civilian	23	Paediatric (100%)	Landmines (87%) UXO (13%)	Retrospective. Single centre Hospital based case series	Injuries and mortality
Celikel et al (2014)(32)	2012	Syria	Civilian	186	Paediatric (22%) Adult (78%)	IEDs/Shelling (67%) GSW (26%) Other/Unknown (7%)	Retrospective. Multi-centre Hospital based mortuary case series	Mortality
Celikel et al (2015)(33)	2012-2014	Syria	Civilian	140	Paediatric (100%)	IEDs/Shelling (70%) GSW (14%) Other/Unknown (16%)	Retrospective. Multi-centre Hospital based mortuary case series	Mortality
Chehab et al (2018)(34)	2009-2012	Afghanistan	Military	81	Paediatric (100%)	IEDs/Shelling (67%) GSW (21%) Stabbing (12%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Cremer et al (2009)(35)	2004-2007	Afghanistan Iraq	Military	2090	Paediatric (100%)	GSW (29%) IEDs/Shelling (24%) Other/Unknown (22%) Non-combat (25%)	Retrospective. Military Trauma Registry	Injuries and mortality
Dua et al (2013)(36)	2006-2008	Iraq	Military	25	Paediatric (100%)	IEDs/Shelling (72%) GSW (28%)	Retrospective. Military Trauma Registry	Injuries and mortality
Edwards et al (2012)(37)	2002-2012	Afghanistan Iraq	Military	4913	Paediatric (100%)	IEDs/Shelling (100%)	Retrospective. Military Trauma Registry	Injuries and mortality

Edwards et al (2014)(38)	2002-2012	Afghanistan Iraq	Military	6273	Paediatric (100%)	IEDs/Shelling (23%) GSW (16%) Other/Unknown (4%) Non-Combat (57%)	Retrospective. Military Trauma Registry	Injuries and mortality
Edwards et al (2014)(39)	2002-2010	Afghanistan Iraq	Military	4928	Paediatric (100%)	IEDs/Shelling (100%)	Retrospective. Military Trauma Registry	Injuries and mortality
Er et al (2017)(40)	2013-2014	Syria	Civilian	1591	Paediatric (18%) Adult (82%)	IEDs/Shelling (77%) GSW (7%) Other/Unknown (16%)	Retrospective. Single-centre Hospital based case series	Injuries and Mortality
Fares et al (2013)(41)	2006-2011	Lebanon	Civilian	122	Paediatric (100%)	UXO (100%)	Retrospective. Single centre Hospital based case series	Long term sequelae
Fares et al (2014)(42)	2006-2013	Lebanon	Civilian	29	Paediatric (28%) Adult (72%)	UXO (100%)	Retrospective. Single centre Hospital based case series	Injuries and mortality
Gataa et al (2011)(43)	2005-2006	Iraq	Civilian	551	Paediatric (20%) Adult (80%)	IEDs (82%) GSW (18%)	Retrospective. Multi-centre Hospital based case series	Injuries and mortality
Guerrero et al (2014)(44)	2013	USA	Civilian	11	Paediatric (100%)	IEDs (100%)	Prospective. Community Surveillance	Long term sequelae
Guha-Sapir et al (2015)(45)	2011-2014	Syria	Civilian	78769	Paediatric (16%) Adult (84%)	IEDs/Shelling (75%) GSW (25%)	Grey-literature	Mortality
Guha-Sapir et al (2018)(46)	2011-2016	Syria	Civilian	101453	Paediatric (17%) Adult (83%)	Shelling/Air bombardment (57%) Other/Not specified (43%)	Retrospective. Community Surveillance	Mortality
Gurney et al (2004)(47)	2003	Iraq	Military	78	Paediatric (100%)	IEDs/Shelling (7%) GSW (1%) Other/Not specified (9%) Non-Conflict (83%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Hanevik et al (2000)(48)	1991-1995	Eritrea	Civilian	248	Paediatric (63%) Adult (37%)	Landmines (100%)	Retrospective. Multi-centre Hospital based case series	Injuries and mortality
Harris et al (2009)(5)	2008	Afghanistan	Military	15	Paediatric (100%)	IEDs/Shelling (87%) Other/Not specified (6%) Non-conflict (7%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Hemmati et al (2015)(49)	1988-2013	Iran	Civilian	78	Paediatric (100%)	Landmines (100%)	Cross-section. Community surveillance	Long term sequelae
Hillman et al (2016)(50)	2003-2014	Afghanistan Iraq	Military	27	Paediatric (100%)	IEDs /Shelling (59%) GSW (26%) Non-combat (15%)	Retrospective. Military Trauma Registry	Injuries and mortality
Hinsley et al (2005)(51)	2003	Iraq	Military	79	Paediatric (10%) Adult (90%)	IEDs/Shelling (63%) GSW (37%)	Retrospective Single-centre Hospital based case series	Injuries and mortality
Hodalic et al (1999)(52)	1991-1992	Croatia	Military	1211	Paediatric (13%) Adult (87%)	IEDs/Shelling (95%) GSW (3%) Other/Not specified (2%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Inwald et al (2014)(53)	2011-2012	Afghanistan	Military	112	Paediatric (100%)	IEDs/Shelling (54%) GSW (29%) Non-conflict (17%)	Retrospective Single-centre Hospital based case series	Injuries and mortality
Jaffe et al (2010)(54)	2000-2005	Israel	Civilian	837	Paediatric (14%) Adult (86%)	IEDs (100%)	Retrospective. National Trauma Registry	Injuries and mortality
Jeevaratnam et al (2013)(55)	2010	Afghanistan	Military	88	Paediatric (35%) Adult (65%)	IEDs/Shelling (33%) Non-conflict (67%)	Retrospective Single-centre Hospital based case series	Injuries and mortality
Khan et al (2015)(56)	2010-2011	Pakistan	Civilian	103	Paediatric (16%) Adult (84%)	IEDs (100%)	Retrospective National Trauma Registry	Injuries and mortality
Kinra et al (2003)(57)	1991-2000	Bosnia and Herzegovina	Civilian	4064	Paediatric (14%) Adult (86%)	Landmines (100%)	Retrospective. Community Surveillance	Injuries and mortality
Klimo et al (2010)(58)	2007-2009	Afghanistan	Military	43	Paediatric (100%)	IEDs/Shelling (67%) GSW (5%) Non-combat)28%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Kluger et al (2004)(59)	2000-2003	Israel	Civilian	906	Paediatric (7%) Adult (93%)	IEDs (100%)	Retrospective. National Trauma Registry	Injuries and mortality
Matos et al (2008)(60)	2003-2004	Iraq	Military	1132	Paediatric (3%) Adult (97%)	IEDs/Shelling (64%) Non-combat (36%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
McGuigan et al (2007)(61)	2004	Iraq	Military	99	Paediatric (100%)	GSW (42%) IEDs/Shelling (35%) Other/Not specified (23%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
McKechnie et al (2014)(62)	2008-2012	Afghanistan	Military	766	Paediatric (100%)	IEDs/Shelling (51%) GSW (28%) Non-combat (21%)	Retrospective. Military Trauma Registry	Injuries and mortality
Mirza et al (2013)(63)	2007-2011	Pakistan	Civilian	1142	Paediatric (6%) Adult (94%)	IEDs (100%)	Retrospective Multi-centre Hospital based mortuary case series	Injuries and mortality
Mousavi et al (2015)(64)	2014	Iran	Civilian	78	Paediatric (100%)	Landmines (80%) UXO (20%)	Retrospective. Mixed-method community surveillance	Long-term sequelae/ Injuries and mortality
Naylor et al (2018)(65)	2007-2016	Afghanistan Iraq	Military	3439	Paediatric (100%)	IEDs/Shelling (38%) GSW (20%) Non-combat (11%) Other/Not specified (31%)	Retrospective. Military Trauma Registry	Injuries and mortality
Neff et al (2014)(66)	2001-2013	Afghanistan Iraq	Military	1113	Paediatric (100%)	IEDs/Shelling (56%) GSW (32%) Non-combat (12%)	Retrospective. Military Trauma Registry	Injuries and mortality
Nordmann et al (2010)(67)	2008-2009	Afghanistan	Military	31	Paediatric (100%)	IEDs/Shelling (45%) GSW (32%) Non-combat (23%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Pannell et al (2015)(68)	2010-2011	Afghanistan	Military	263	Paediatric (100%)	IEDs/Shelling (42%) GSW (17%) Non-combat (41%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Pat-Horenczyk et al (2007)(69)	2006	Israel	Civilian	695	Paediatric (100%)	IEDs (100%)	Retrospective. Mixed-method community surveillance	Long term sequelae
Patregnani et al (2012)(70)	2002-2009	Afghanistan Iraq	Military	744	Paediatric (100%)	IEDs/Shelling (43%) GSW (26%) Non-combat (31%)	Retrospective. Military Trauma Registry	Injuries and mortality
Pearce et al (2015)(71)	2011-2012	Afghanistan	Military	281	Paediatric (100%)	IEDs/Shelling (47%) GSW (13%) Non-combat (35%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Poor Zamany Nejat et al (2016)(72)	2015	Iran	Civilian	41	Paediatric (100%)	Landmines (100%)	Retrospective mixed-method community surveillance	Long term sequelae
Quintana et al (1997)(73)	1996	USA	Civilian	66	Paediatric (100%)	IED (100%)	Retrospective. National Trauma Registry	Injuries and mortality
Schauer et al (2018)(74)	2007-2016	Afghanistan Iraq	Military	3388	Paediatric (100%)	IEDs/Shelling (43%) GSW (22%) Non-combat (35%)	Retrospective. Military Trauma Registry	Injuries and mortality

Smith et al (2014)(75)	2003-2011	Afghanistan Iraq	Military	813	Paediatric (6%) Adult (94%)	IEDs/Shelling (77%) GSW (23%)	Retrospective. Military Trauma Registry	Injuries and mortality
Spinella et al 2008(76)	2001-2007	Afghanistan Iraq	Military	1305	Paediatric (100%)	Trauma (Unspecified) (100%)	Retrospective. Multi-centre Hospital based case series	Injuries and mortality
Terzic et al (2001)(77)	1991-1995	Bosnia Croatia	Civilian	92	Paediatric (100%)	IEDs/Shelling/UXO (100%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Thompson et al (2017)(78)	2006-2013	Afghanistan	Military	295	Paediatric (100%)	IED (68%) UXO (4%) Other/Not specified (28%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Villamaria et al (2014)(79)	2002-2011	Afghanistan Iraq	Military	155	Paediatric (100%)	IEDs/Shelling (58%) GSW (37%) Other/Not specified (5%)	Retrospective. Military Trauma Registry	Injuries and mortality
Waisman et al (2003)(80)	2000-2002	Israel	Civilian	160	Paediatric (100%)	IEDs (67%) GSW (25%) Other/Not specified (11%)	Retrospective. National Trauma Registry	Injuries and mortality
Walker et al (2010)(81)	2006-2007	Afghanistan	Military	78	Paediatric (100%)	IEDs/Shelling (64%) GSW (37%) Other/Not specified (5%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Wilson et al (2013)(82)	2010-2011	Afghanistan	Military	41	Paediatric (100%)	IEDs/Shelling (47%) GSW (12%) Non-combat (42%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Woods et al (2012)(83)	2003-2009	Afghanistan Iraq	Military	176	Paediatric (100%)	IEDs/Shelling (59%) GSW (21%) Non-combat (20%)	Retrospective. Military Trauma Registry	Injuries and mortality

3.1 Demographics

Following the use of explosive weaponry by non-state actors against civilians, the most commonly injured paediatric cohort are males aged 10-18 years old(9,12,80), while children involved in conflict and ERW blast injuries were generally aged between 4-10 years old(37,81). Perpetrators target busy areas such as restaurants and nightclubs which older children and adolescents might frequent (10,12,80), while cultural factors within LMICs in these social areas result in a predominantly male cohort (9,10,25,44,54,56,59,63,69,80). Similar gender finding are observed in children following conflict and ERW related injuries where all studies showed male predominance in victims, with over 70% male in three quarters of the studies (Figure 1).

(Figure 1. Gender differences in in casualties following blast)

ERW contribute considerable morbidity and mortality both during and following conflict. As seen in figure 2, children were more likely to be injured by UXO compared with adults, while landmines affected a predominately adult cohort (11,13,16,18,20,22,23,31,57).

(Figure 2. Percentage of Casualties (injuries and fatalities) by specific modalities)

UXOs have been described as small, colourful and toy-like, promoting child interaction and subsequent injury from handling, resulting in often fatal upper limb, head, neck or chest injury(18,31,41,84,85). Due to the social nature of children, these interactions commonly occur in groups, leading to multiple casualties in 45-63% of events involving children compared to 30-40% in adults(20,57,64).

Occupation and education play a role in ERW injuries. It is common for children in LMICs, particularly males, to assist their family with herding and farming as opposed to attending school. This may affect the likelihood to exposure to ERWs through increased freedom to roam where such devices are present(25,42,64,72). A lack of formal education impacts the

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3 child's ability to read warning signs; only 6-22% of victims were aware ERWs were
4 present(27,80) and of these, only 0-11% had received ERW risk education(23,25,27,80).
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7 Children are particularly vulnerable to wide-area explosives such as aerial bombardment and
8 shelling, particularly in the primarily urbanised environments of modern conflicts. In the Syrian
9 Civil War, three quarters of wide-area explosives were used in civilian residential areas that
10 children frequent, with these mechanisms responsible for 82% of child deaths(45,46).
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14 The following section reviews what is known of mortality in children before reviewing injury
15 types.
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18 19 **3.2 Mortality** 20 21

22 Comparison of paediatric wartime mortality data is difficult as many studies do not differentiate
23 mechanism of injury. Edwards et al(86) study on 4,913 children between 2002-2010
24 presenting with blast injuries remains the single largest data set. The reported mortality rate
25 of 8% matches well with the mortality rates of 6-9% quoted in paediatric trauma deaths from
26 Iraq and Afghanistan, although these studies displayed all trauma mechanisms as opposed to
27 specifying blast trauma(15,27,30,35,39,62). Between 2006-2013, Thompson et al. (78) noted
28 a mortality rate over double of that quoted by Edwards et al. following paediatric blast injury
29 in Afghanistan (18%). Operational tempo and the increasing use of IEDs have been
30 hypothesized to underlie these discrepancies in mortality(78).
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37 Age related variation in mortality has been described. Matos et al noted mortality was highest
38 at 24% in young children (5-8 year old)(60) while Schauer et al and Spinella et al found
39 greatest mortality in 0-4 years(74,76). Similarly, Borgman et al and Matos et al noted that
40 children <8 years old had increased trauma mortality compared to 8-16 year olds (10-18% vs
41 4-7%)(28,60), while Spinella et al noted a similar increase in mortality in young children (<6
42 year old) compared to 6-16 year olds (11% vs 4%)(76). Few studies directly compare adult
43 and paediatric mortality, and comparisons between studies are difficult due to methodological
44 differences. What is common is that mortality in children following combat related trauma is
45 considerably higher than that of paediatric non-combat trauma (2-3%)(87) and adult military
46 combat casualties (1-3%)(88,89).
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54 A wide range of paediatric mortality is reported following mine strikes, ranging from 4-
55 46%(13,18,20-24,31,41,84). Shuker et al(90) suggested that approximately half of paediatric
56 victims die within minutes of mine explosion, likely due to lacerations to the head, major blood
57 vessels or vital organs causing non-survivable injuries, in keeping with adult literature(88,89).
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3 Time critical injuries following blasts may represent particular problems in LMIC's, where pre-
4 hospital evacuation chains may be protracted. Coupland(91) noted that in 1991, only 14% of
5 paediatric and adult ERW victims were admitted in under six hours, while the majority (58%)
6 were admitted between 6-24 hours and 28% presented after 24 hours. Even in recent conflicts,
7 Bitterman et al(26) found <10% of children presented within 1 hour, with over a third presenting
8 after 6 hours. Protracted evacuation of paediatric victims add to blast mortality, reinforced by
9 studies observing a 85-91% mortality of children either at scene or en-route to health
10 facilities(23,90).
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17 **3.3 Injury types and mortality**

18 **3.3.1 Vascular damage**

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20 Penetrating injuries occur in 38-76% of blast-exposed children (9,10,15,16,27,35,68,80), with
21 incidence greater in older children aged 10-16 compared to 0-10 year olds (65-83% vs 47-
22 63%)(54,60). In keeping with penetrating injury patterns, vascular injury was observed in 3-
23 12% of children following blast trauma (9,16,79,80), considerably higher compared to non-
24 blast conflict trauma where vascular injury occurred in 0.6-1% of paediatric
25 victims(9,10,59,61,79).
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32 Vascular damage and subsequent haemorrhage following explosions have been identified as
33 a significant cause of childhood fatalities, ranging from the primary cause of death in 21-38%
34 during the Syrian Civil War(32,33) to 63% following IED and suicide attacks in Pakistan(63),
35 while mortality rates following penetrating injuries in civilian settings are considerably lower
36 (5%)(79). Extremity trauma was most highly associated with vascular injuries, with the majority
37 of vascular injuries occurring in the lower limb (38-58%) followed by the upper limbs (25-
38 28%)(36,79). This is in keeping with adult data where 54% of injuries were sustained to the
39 extremities(88). Despite its high prevalence, extremity vascular wounds confer reduced risk of
40 death compared to vascular damage within the torso, attributed as the primary cause of death
41 in 71% of paediatric deaths and conferring a four-fold increased risk of death compared to
42 extremity vascular injuries(79).
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50 Data on vascular damage is clear: older children and adolescents sustain similar rates of
51 vascular injury to adults, particularly to the extremities, while mortality following penetrating
52 trauma is primarily the result of injuries to the vasculature within the torso.
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57 **3.3.2 Head injury**

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3 The prevalence of head injuries following blasts are diverse, ranging from 6-54%
4 (10,12,15,17,19,26,30,34,35,37,40,51–53,61,79,80), while adult combat data ranges from 16-
5 29%(88). This variation is due to the heterogenous definitions of head injury described in these
6 studies, with few studies differentiating between superficial scalp wounds, blunt traumatic
7 brain injury (TBI) or penetrating TBI. Where head injuries were documented, TBI was recorded
8 in 21-62% of paediatric victims, of which 38-39% were defined as penetrating(42,52,80).
9 Unsurprisingly, papers noted over double the incidence of paediatric penetrating head injury
10 in blast trauma compared to mainly blunt civilian trauma (13% vs 6%), while the reverse was
11 true in closed head injuries, with half the incidence of closed head injuries in blast injuries
12 compared to civilian trauma (22% vs 44%)(9).

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20 Cerebral haemorrhage and direct cranial damage following blast have been attributed as a
21 leading cause of death in children, responsible for 46-71% of fatalities (36–38,43,101).
22 Creamer(38) noted penetrating wounds to the head accounted for 44% of child deaths in the
23 emergency department while open skull fractures with cerebral evisceration was documented
24 in 88% of paediatric fatalities following the 1995 Oklahoma City bombings(102). While
25 penetrating head injuries undoubtedly carry high mortality, Woods(83) noted that 8 children
26 survived to hospital discharge despite penetrating head injuries deemed initially unsurvivable,
27 suggesting such are not unequivocally fatal.

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33 Er et al(40) noted that children were more likely to be injured in the head compared to adults
34 (54% vs 40%) following aerial and shelling during the Syrian Civil War, while young children
35 aged between 0-4 year old were more likely to undergo neurosurgical procedures compared
36 to other ages(39,58), 48% of which were craniectomies or craniotomies for penetrating brain
37 injury, mainly secondary to IED blasts(58). Suggested reasons for this increase may relate to
38 anatomical predispositions, particularly in infants, such as large head to body ratios in addition
39 to reduced skull rigidity(54) as well as the relatively shorter distance from the head to ground-
40 based ERW and IEDs compared to adults(18,37,54,85,90).

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47 There is a clear lack of studies investigating long term outcomes following blast- associated
48 head injuries. While significant cognitive, intellectual and functional sequelae arising from non-
49 blast TBI (nbTBI) have been described, controversy exists as to whether nbTBI is analogous
50 to blast-induced TBI(92), and the paucity of paediatric data means this comparison is even
51 more problematic.

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56 A unifying message is that head injuries are associated with high morbidity and mortality in
57 paediatric blast trauma, while the long term consequences remain largely unknown. Head
58 injuries are commonly penetrating compared to civilian practice, and increased operative
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3 demand in infants and toddlers for neurosurgical procedures may stretch medical service
4 expertise.
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7 8 **3.3.3 Facial and ocular injuries** 9

10 Blasts result in injury to the face in between 27-48% of paediatric victims, compared to 12%
11 resulting from GSW(12,37,53) and 10% in adults(88). Relative to other blast related injuries,
12 facial injuries in isolation are associated with reduced mortality(37). However, Gataa (43)
13 noted that of the patients presenting with facial injuries, 29% had concomitant eye injury, 22%
14 had TBI, while life-threatening facial bleeding occurred in 10% of patients. In addition to
15 physical sequelae, facial injuries are associated with functional and psychological disorders
16 stemming from stigmatisation of disfiguring injuries with implications for future social,
17 economic and marital prospects(43).
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20 Despite only comprising of 0.3% of the anterior body surface, the eye is sensitive to blast
21 injury, with ocular injuries in 4-28% of children following trauma related to combat or ERW
22 (15,17,19,26,34,35,42,61,64). In keeping with patterns of facial injury, an increased
23 prevalence of eye injury is associated with blast injuries compared to GSW (13% vs 3%)(12).
24 Landmines are often associated with multiple foreign bodies on the conjunctiva, cornea and
25 sclera, in addition to sight-threatening injuries such as enucleation or eye globe
26 perforation(31). Monocular enucleation was observed in 4%, while bilateral enucleation, and
27 hence blindness, was more common (14%)(31,64). When compared to adult victims of
28 landmines and cluster bombs, children have more eye injuries (14% vs 8%)(57) as well as
29 twice the prevalence of eye globe perforation (28% vs 14%)(40) and complete loss of vision
30 (21 vs 10%)(18). Without adequate support, both monocular and bilateral vision loss may
31 translate to developmental and educational deficiencies in the growing child.
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34 Facial and eye injuries are frequent following exposure to blasts, and should raise suspicion
35 of intracranial injury. Important are the social and education implications of these disfiguring
36 injuries in the growing child.
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39 40 **3.3.4 Torso Injuries** 41

42 Following blast injury, trauma to the torso is common, varying from 12-46% between studies
43 (12,15,17,19,26,30,31,35-37,40,51-53,63,79) and peaking in 5-10 year olds(54,80). Er et
44 al.'s (40) study on civilian paediatric injuries during the Syrian Civil War noted that the
45 abdomen was less commonly injured compared to adults (12 vs 20%), while chest injury with
46 accompanying lung contusion was present in 51% of children with torso injuries, compared to
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3 35% in adults. Both chest and abdominal injuries from blast are typically classed as
4 'severe'(37). Abdominal injuries accounted for 18-19% of injury specific deaths following blast
5 in the paediatric population, while chest injuries have been attributed to 8% of deaths in the
6 ED(35). Explanations for this susceptibility to severe and life threatening torso injuries include
7 a lack of body armour compared to adult combat victims and the observation that children
8 have flexible rib cages allowing greater damage to underlying structures without rib fracture,
9 contributing to the increase in lung contusion observed(79).

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15 When organ specific injuries were examined, blast was most likely to cause open penetrating
16 wounds of the bowel and intra-abdominal organs, affecting the small intestine in over a third
17 (34%) and the liver, spleen or pancreas in 36%(14,35,67). Where internal organ damage was
18 sustained, injury specific mortality almost doubled from 15 to 29%(32). These injuries were
19 frequently contaminated due to bowel rupture, requiring multiple procedures and a high rate
20 of antibiotic usage(77). The thinner abdominal walls, reduced intraabdominal fat and larger
21 solid organs relative to the body cavity increases likelihood of visceral damage following
22 penetrating trauma, while delayed signs of visceral damage support the role of repeated
23 examination and radiological input, even in the absence of external damage.

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30 In the context of total operative procedures performed, laparotomies comprised a significant
31 component of total surgical workload, encompassing 12-23% of all paediatric procedures
32 performed(62,78,93). Children were more likely to require laparotomies following combat
33 trauma compared to paediatric non-combat, and primarily blunt, abdominal trauma (13 vs 2%).
34 Children in combat zones were also twice as likely to undergo laparotomies compared to US
35 service personnel (12% vs 6%)(76). In addition to the high prevalence of abdominal injuries,
36 children frequently swallow air when frightened or in pain, resulting in gastric dilation. As well
37 as increasing vomiting risk, this may erroneously suggest abdominal injury(90) and lead to
38 laparotomy. Despite this, Arafat et al(14) noted that only 8% of laparotomies were negative,
39 supporting the role of explorative laparotomies in penetrating trauma following blasts.

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47 Compared to both adults and children in non-conflict settings, the blast injured child is more
48 likely to sustain injuries to the chest. While abdominal injuries are less frequent, they are more
49 likely to involve visceral damage and require operative management compared to adult
50 combat trauma.

51 52 53 54 55 **3.3.5 Extremity injury**

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Extremity injury is one of the defining features following blast related trauma. Extremity injuries
within conflict zones are observed in just under half of children (45%), its prevalence

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3 increasing in blast injuries (69%)(53), with a retrospective study finding 100% of traumatic
4 amputations and 96% of bone injuries to hand and foot were secondary to blast injuries(19).
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7 Studies describe extreme variation in the prevalence of upper limb injuries following blasts,
8 ranging from 6-74% (11,13,15–17,19,26,30,31,51,52,62,63,73,78–80), with the greatest
9 upper limb injury reported following UXO and cluster munition strike(31,41). Compared to adult
10 and particularly following ERW blast, children were more likely to sustain upper limb injuries
11 (18,20–23,63) with a corresponding increase of 150-300% requiring operative amputation,
12 typically at the level of the finger (16,21,22,48). Traumatic amputation of the upper limb was
13 common and limited to the hands in 44-94% of children sustaining upper limb injuries(17,31),
14 while trans-radial and trans-humeral amputation was less frequent (14-34%)(52,62) but were
15 more likely to be bilateral(64). Arm fractures necessitating surgical fixation were observed in
16 45%(73), while upper limb vasculature was commonly disrupted(36,52,79).
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24 Similarly, prevalence of lower limb injuries shows variation between studies on blast affecting
25 25-86% of children(11,15–17,26,30,31,51,52,62,63,73), with landmine strikes particularly
26 associated with lower limb injury(11,16,31); 20-29% required operative amputations, normally
27 at the trans-tibial plane(16,17,64). Lower limb injuries were less common in children compared
28 to adults(18,20,22–24), with incidence lowest in 0-3 year olds(54), while increasing in
29 adolescents to mirror adults(18). Traumatic amputations were less frequent compared to the
30 upper limb, occurring in 14-35% of lower limb injuries(31,52,62).
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36 Landmines drive debris, footwear and clothing upward between planes of the soft tissues and
37 bone, leading to degloving injuries of the leg, perineum and lower abdominal viscera, as well
38 creating serious potential for soft tissue and bone infection in the remaining limb(85,91). While
39 large bony defects of the lower limb are problematic in children(94), reconstruction with limited
40 shortening (<2 cm) has been associated with good outcomes, with the capability for highly
41 active growth plates to remodel and compensate for this (19,95). However, 75% of new growth
42 occurs in the distal femur and tibia growth plates, with the distal limb most prone to explosive
43 disruption(85).
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50 The long term physical, psychosocial and financial repercussions of amputation must not be
51 underestimated. Physical complications are greatest following TA and below knee
52 amputations, and include anterior and varus bowing, heterotopic ossification and osseous
53 overgrowth requiring operative or prosthetic revision(96). Overgrowth is particularly
54 problematic in younger patients (under 12 years), with 15% of patients sustaining amputations
55 requiring re-vision of their stump. Protracted phantom limb sensation (PLS) and phantom limb
56 pain (PLP) is reported in over 50% of children following blast related amputation, similar to
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3 that seen in adult literature following blasts(97), yet over five times higher than in children
4 requiring amputation following non-traumatic indications such as malignancy. Increased PLS
5 has been reported in lower limb amputations, while PLP was increased in upper limb
6 amputations (22,100). Social acceptance of the child amputee is culturally specific, with
7 stigmatisation in certain cultures negatively impacting the child's psychological, social and
8 educational status(98). While there is a paucity of outcome and long term costing studies in
9 LMICs, the financial burden of prolonged rehabilitation and repeated revision of prosthesis on
10 the children and host country's health system is likely to be considerable(98).

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17 Like adults involved in blast trauma, older and adolescents children are prone to extremity
18 injury, particularly of the upper limb, while infants and toddlers experience less extremity
19 injuries. Limb injury causes diverse complications in the growing child with increased
20 requirement for re-revision compared to adults.
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23 24 25 **3.3.6 Burn injuries**

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27 Multiple retrospective studies have noted that the majority of burns in children result from
28 civilian mechanisms such as scalding, open fires and flash burns from household cooking
29 fuels (28,35,47,99,100), while approximately 9-12% is the result of high-order explosives
30 observed in combat blast modalities(47,100), less than observed in adult combat populations
31 (52%)(101). Unlike civilian mechanisms however, blast-induced burns rarely occur in isolation,
32 with multidimensional injuries playing a significant role in the child's prognosis(55,80,100).
33 While post-mortem findings following the Syrian Civil War attributed only 0.5% of deaths being
34 secondary to burns(32), conflict-related burn victims had higher mortality compared to non-
35 conflict related burn victims (47% vs 3%)(99), and significantly greater than blast related burns
36 in adult military populations (5%)(101). Severe burns following blasts were sustained in 30%
37 of children, and fatal in 36-40%(30,37).
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46 Creamer(38) noted the median age of burn victims as 6 years old. At this young age, the
47 anatomical disproportionality of the child increases the total body surface area (TBSA),
48 resulting in significant burn surface area (BuSA). Thus, approximately half of paediatric burns
49 in conflict zones result in BuSA >15% (32,127), while 13% of children have BuSA exceeding
50 40%(127). A high BuSA exceeding 40% has been linked to myocardial damage and
51 hypotension, making hemodynamic management challenging, while complications including
52 nosocomial infection of the burn eschar and pneumonia are not uncommon(99). Within LMICs,
53 protein loss and weight based fluid resuscitation is complicated by malnourishment, while cold
54 fluids may accentuate hypothermia(47).
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3 In conflict related burns, the head and neck are most frequently affected, potentially leading
4 to thermal inhalation injuries(55,100). Thermal inhalation injuries in paediatric victims are
5 difficult to assess, and clues to inhalational injuries such as increased respiratory rate may be
6 incorrectly interpreted in the context of physiological age discrepancies. In addition the
7 paediatric subglottis represents the narrowest section of the upper airway, and deteriorates
8 rapidly from burn-induced laryngeal oedema, especially in the context of failed intubation
9 attempts(102) leading to rapid oxygen desaturation. Between 21-33% of children were
10 identified as having inhalational injuries requiring pre-emptive or immediate intubation to
11 protect the airways(55,61), similar to that seen in adult combat casualties (26%)(101). Of this
12 paediatric cohort with inhalational injuries, 39% died(55), significantly greater than in adult
13 populations (4%)(101).

21 Prognosticating factors noted for burns include increased time to presentation, prolonged
22 hospital length of stay and requirement for critical care input(99). This relates to the resource-
23 intensive management of the paediatric burns patient. Like adults, hospital length of stay for
24 burns patients are 2-3 times that of the general paediatric population(15,100), while ICU
25 requirements are increased, particularly in burns secondary to blast injuries(99,100).
26 Operative demands of paediatric burn victims are significant. Children aged 6 months to 3
27 years were between 4-14 times more likely than adults to require surgical input , reflecting the
28 significant burden of burns (39% of this cohort compared to 2-6% in adults(103)). While other
29 conditions may be treated by a single operation, burns often require serial procedures(103),
30 with an average 2 operations per patient. This creates a disproportionate operative volume in
31 both adults and paediatric patients compared to other surgical emergencies(103). Burns
32 induced by blast injuries require more escharotomies (27% vs 4% $P<0.001$) and fasciotomies
33 (67% vs 30% $P=0.002$) when compared to civilian burn mechanisms(99).

43 Additionally, the requirement for post-operative support and rehabilitation add to the resource
44 requirements. Children are rarely left without functional sequelae, with limited joint mobility
45 and impaired tactile sensation presenting significant future challenges for rehabilitation(104),
46 while high rates of psychological morbidity including suicidal ideation have been reported in
47 adolescents(105). Under-resourcing psychological and functional rehabilitation will likely lead
48 to high rates of morbidity and mortality(103). The degree to which these services are available
49 within conflict zones and LMICs is uncertain. Ethical questions naturally arise when performing
50 interventions where health systems are unlikely to address a child's long term needs.
51 Examination of existing paediatric burn services within zones of interest and longer term follow
52 up of paediatric blast burn patients are required to determine the problems and needs for this
53 cohort.
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3.4 Service provision

Relative to total admissions, paediatric victims affected by blasts constitute a disproportionately large resource burden on operative workload, as well as intensive care and hospital beds. Approximately 47-82% of paediatric blast victims require surgery(14,15,54,78,80), particularly adolescents(54). The requirement for multiple operative procedures were common in the paediatric cohort, especially in burn and orthopaedic surgery due to the requirement for surgical revision (34-80% of children required ≥ 2 procedures(15,17,19,30,34,35,37,67); 25% required ≥ 4 procedures)(35). Operative requirement was greatest in 9-14 year olds, requiring on average 5 procedures per patient, prolonged ICU and hospital stay, while 0-3 year olds required the least operative management(39). This study suggested the reduced requirement for operative input in 0-3 year olds may be due not only to the reduced burden of extremity injuries requiring repeated debridement, but potentially because the equipment was inappropriate for this young cohort. This is supported by observations that infants and young children aged 0-10 years old with an Injury Severity Score ≥ 15 were 4x less likely to go to surgery compared to adults, while adolescents (11-15 years) were 2x more likely to receive operative input(54).

Multidisciplinary surgical services were required in 80% of patients, with orthopaedic, plastic, general neurosurgical, ophthalmic and vascular surgeons often working in partnership(52). Debridement and primary skin closure represented the most common procedure, in 35-100% of studies(15-17,51,62,73,76,78), in keeping with shrapnel injuries leading to multiple and frequently contaminated superficial injuries(51,73). Children are likely to do well with thorough debridement, with well perfused tissues allowing optimal healing and scar formation(19,95).

Retrospective studies of US military medical treatment facilities (MTF) in Afghanistan have found that while children comprised only 3-6% of their total admissions, this demographic required approximately double the total bed spaces (7-11%)(27,38,61), and on average 3x the length of stay (LOS) of coalition troops admitted over the same time period(27,76). Approximately 40% of paediatric admissions required a LOS exceeding 7 days, while, in half, the LOS exceeded 14 days(10,80). Spinella et al noted that while children aged 11-17 were the greatest proportion of children occupying beds, <1 year old cohort had the longest stay(76). This contrasts with other studies finding young children <8 years old had the shortest LOS, while children(8-14 years old) had the longest(27,37).

A similar burden is observed in the intensive care unit (ICU), with between 20-45% children requiring ICU admission(5,14,15,40,55,61,67,74,80), the majority following explosive or ballistic trauma. Children were often younger (0-10 years old)(54), with one recent study noting

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3 children aged <1 year and 1-4 years most often requiring admission(53 & 66%
4 respectively)(74). Children under 8 required a ICU LOS over twice that of children aged >8
5 years (60). Harris et al(5) noted that despite representing only 12% of admissions, children
6 occupied on average 35% of ICU beds, with a brief surge in numbers resulting in 100%
7 occupancy from children, the majority requiring ventilatory and inotropic support. This
8 specialised service was often provided by non-paediatric experts, which could result in 2
9 healthcare providers per paediatric patient(5). Ventilatory equipment is often age specific, and
10 although multiple examples of ingenuity and adaptation of adult equipment exist(5,67),
11 children may overwhelm the unprepared MTF.

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18 One of the key challenges is providing sustainable health services in the host country. MTFs
19 may be capable of delivering exceptional paediatric care in the acute phase following blasts,
20 but recovery from morbidity is dependent on long term rehabilitation(95) normally provided by
21 the host country. Not only can this place exceptional strain on local health authorities, but if
22 provisions are not available, the child is likely to undergo a protracted decline(5,95).

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Reasons for the high rate of admission and prolonged stay may be multifactorial. Admission
criteria for host nationals to a coalition MTF typically require threat to life, limb, or eyesight,
with resulting prolonged stay. Interestingly however, children with mild to moderate traumata
are three times more likely than adults to be admitted (54). This may reflect a lack of certainty
in initial assessment of injury severity from health practitioners unaccustomed to dealing with
children. Within conflict zones, rearwards evacuation of civilians is not always possible, and
health interventions such as ventilatory support may not be sustainable by host countries
without deterioration in service standards, leading to prolonged admission until the child can
be safely moved(5).

Following up recovery is a recurring theme when exploring long term challenges of blast
injuries in children(6). Children are a complex cohort to monitor. Geographical displacement,
particularly in the context of a conflict, increases the likelihood of this vulnerable cohort being
lost to follow-up. This can impact not only the child's rehabilitation and coordination with local
health authorities, but also cause difficulty in assessing long-term functional outcomes which
are needed to detect future health needs. Increasingly there is recognition of the need for
formalised trauma registries accessible in the host country, assisting the follow-up of this
vulnerable demographic(6,37,38,61).

4. Summary

Compared to adults:

- Mortality due to blast injuries decreases with increasing age.
- UXO injuries are more prevalent in the child and result in higher numbers of multiple casualties per incident.
- Vascular injury due to blast is similar between older children/adolescents and adults.
- Male children are more likely than females to be injured by blast, in keeping with adult demographics.
- Children have a higher incidence of head injuries, facial injuries, eye injuries and chest injuries than adults.
- Abdominal injuries, although they occur less frequently, are more likely to require operative management.
- Upper limb injuries and amputations are more frequent; the opposite is true for lower limb injuries.
- Burns injuries are excessively severe for young children, reflecting the anatomical disproportionality of the very young, and fatalities are far higher for those with inhalation injuries.
- Children have a disproportionate requirement for both operative and non-operative service resources.

5. Conclusion

Apart from their focus on paediatric blast, all the papers in this review have one thing in common. Their research is based on those child patients injured by blast in conflict zones, post-conflict zones and low resource environments. Most paediatric blast injury is inflicted in these settings but is not exclusive to them. In Britain in May 2017, a bomb detonated at the Manchester Arena killing 23 people and injuring 139, most of whom were children. The attack placed a sudden and significant burden on medical services in the city, which had no experience of paediatric blast injury in the 21st century, let alone on this kind of scale.

Wherever in the world they live, and whatever the circumstances of the explosion, the social and anatomical profile of children makes them uniquely vulnerable to one of the most complex and demanding trauma conditions that any medical professional or system can treat. This paper has characterised paediatric blast as a diverse injury pattern, which must be seen as distinct from its adult equivalent. This pattern should be fully understood from point of wounding through the post-operative and rehabilitation phases of treatment. This continuum approach would enable both better long-term care of the patient, and improved support of medical systems bearing the intense burden of that care.

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3 It remains to be seen whether the monitoring of the long term effects of paediatric blast injury
4 in well-resourced environments is any better than that in areas of instability. Monitoring of
5 patient outcomes should be integrated with the monitoring of treatment so that relevant
6 practice and skills can be continually assessed. It is urgent that the understanding of
7 paediatric blast injury is given focus and structure, not just for the likely significant patient
8 cohort of the future but for those suffering today as blast injured children surviving into blast-
9 blighted adulthood, wherever they live in the world.
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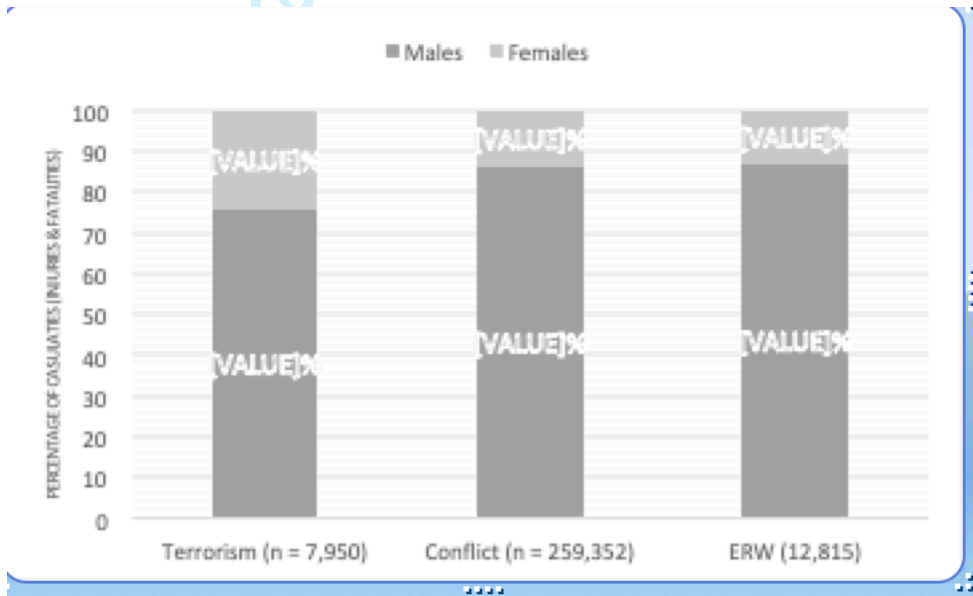


Figure 1. Gender differences in in casualties following blast

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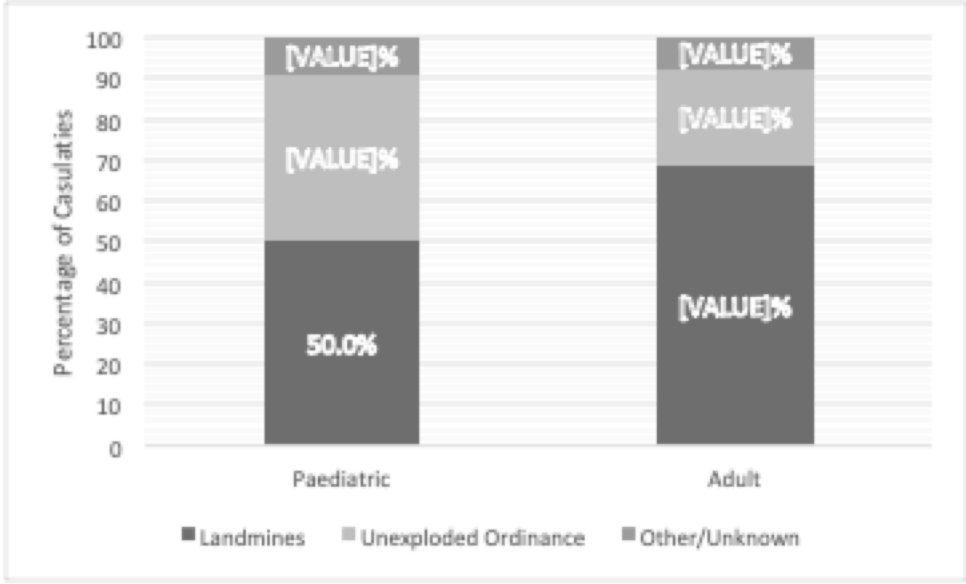


Figure 2. Percentage of Casualties (injuries and fatalities) by specific modalities

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BMJ Paediatrics Open

Blast Injuries in Children: a mixed-methods narrative review.

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41 **Patient and public involvement statement:**

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43 **No patients or members of the public were involved in this review.**
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Key questions

What is already known on this topic?

- Approximately one in six children live in conflict zones, where exposure to blast injuries is not uncommon. Blast injuries have the potential to inflict significant mortality and morbidity upon the global paediatric population living in conflict zones.
- Describing the characteristics of injuries sustained by the paediatric population is essential in advancing local and global health policies. Despite this, common themes related to paediatric injury following to blasts are poorly described.

What this study hopes to add?

- Paediatric victims are most likely to be male, with victims following conflict and explosive remnants of war (ERW) typically 4-10 years old. Of these victims, arable occupation and poor educational status is related to level of exposure.
- Variability in mortality exists between age groups, with increased mortality in children under 8 years old compared to older populations (10-18% vs 4-7%). As with adults, proximity to health care facilities strongly influence mortality in these populations.
- Head injuries are the leading cause of death in 46-71% of paediatric victims, and strongly associated with facial and ocular injuries conferring significant social and economic implications to the victims.
- Penetrating trauma associated with vascular injuries occurs in 3-12% of children exposed to blast injuries, considerably higher than non-blast injuries from conflict (0.6-1%), with haemorrhage a major cause of paediatric fatalities. Injuries to the torso are associated with a high surgical workload, with children twice as likely to require surgical intervention following blast injuries compared to adults (12% vs 6%).
- Injuries to the extremities are seen in approximately half of children exposed to blast trauma, with upper limb injuries requiring between 1.5 to 3 times more operative intervention compared to adults. Functional repercussions of these injuries are significant, with 15% of traumatic amputations in the lower limb frequently requiring operative and prosthetic re-revision.
- Burn injuries following explosive injuries are less frequently seen compared to adults (9-12% vs 52%), but confer a significant mortality of 36-47%, higher than that seen in non-explosive related burns (3%) and adults (5%). These patients commonly require reoperation and intensive rehabilitation, adding to the burden upon services.
- An influx of paediatric patients can rapidly overwhelm health facilities, with between 47-82% of children requiring surgical intervention, of which 25% required over 4 procedures. Greater requirement for intensive care support in addition to prolonged inpatient and rehabilitative stays contributes to considerable service strain.

Abstract

Background and significance. Blast injuries arising from high explosive weaponry is common in conflict areas. While blast injury characteristics are well recognised in the adults, there is a lack of consensus as to whether these characteristics translate to the paediatric population. Understanding blast injury patterns in this cohort is essential for providing appropriate provision of services and care for this vulnerable cohort.

Methods. In this mixed-method review, original papers were screened for data pertaining to paediatric injuries following blasts. Information on demographics, morbidity and mortality and service requirements were evaluated. Patient and public involvement statement: No patients or members of the public were involved in this review.

Results. Children affected by blast injuries are predominantly male and their injuries arise from explosive remnants of war, particularly unexploded ordnance. Blasts show increased morbidity and mortality in younger children, while older children have injury patterns similar to adults. Head and burn injuries represent a significant cause of mortality in young children, while lower limb morbidity is reduced compared to adults. Children have a disproportionate requirement for both operative and non-operative service resources, and provisions for this burden are essential.

Conclusions. Certain characteristics of paediatric injuries arising from blasts are distinct from that of the adult cohort, while the intensive demands on services highlights the importance of understanding the diverse injury patterns in order to optimise future service provisions in caring for this vulnerable cohort.

Introduction

Approximately one in six children live in conflict zones, with the main global burden borne by citizens of low and middle income countries (LMICs)(1). Children enmeshed in conflict and post-conflict zones are frequently exposed to high-order explosives (HE), either through explosive remnants of war (ERW) such as landmines and unexploded ordinance (UXOs), military ordinance such as shelling and aerial bombardments or acts perpetrated by non-state actors such as improvised explosive devices (IEDs) and suicide bombing(2). HE can inflict unique and unusual injuries upon the child through the blast over-pressure wave (primary blast injury), energisation of materials causing fragmentation (secondary blast injury), bodily displacement or crush injuries (tertiary blast injuries) and through burns, inhalation, toxic or psychological trauma (quaternary blast injuries)(3).

Article 3.3 of the UN Convention on the Rights of the Child (UNCRC) states that medical care of the child be delivered and supervised by providers competent in that field(4). However, paediatric care in conflict zones is often delivered by personnel for whom experience of dealing with paediatric blast injuries is unusual(5). Primary studies increasingly recognise the complex patterns of injury sustained in the adult population following blast exposure(3), however there is a lack of consensus as to whether applying lessons learnt from the adult population translates appropriately into paediatric cohorts(6). Bree et al(7) argue that principles for life-saving interventions, such as prioritising catastrophic haemorrhage, airway, breathing and circulation are just as applicable in children as adults. Conversely Fendya et al(8) contend that directly applying adult trauma principles to the paediatric population neglects the social, anatomical, physiological and psychological differences between adults and children, affecting the validity of these inferences.

While primary studies have described injuries sustained by the blast injured child, no study has attempted to synthesise the data to identify recurrent characteristics in this vulnerable cohort. Understanding the characteristics of such injuries to the paediatric population will advance efforts to prevent, mitigate, and treat these injuries in domestic and deployed health systems(3). The aim of this review is to provide an overview of injury patterns and challenges in caring for the blast-injured child, in order to define future research needs for protection, mitigation, immediate medical treatment, and rehabilitation.

Methods

In this mixed-methods review, original peer-reviewed quantitative, qualitative and mixed-method observational studies, in addition to grey literature, were screened for data on

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3 explosive injuries in paediatric cohorts. By utilising all study designs, greater capture of
4 relevant literature was achieved, although this meant the data was unsuitable for a formal
5 systematic review. PubMed and Scopus (including Embase) were searched. Search terms
6 including “Paediatric” OR “Pediatric” OR “Child*” OR “Children” AND “Blast” OR “Explosi*” OR
7 “Explosion” were used to capture potential studies. Articles had to be written in English and
8 published before December 16, 2018. Studies involving adult as well as children were
9 included, in addition to articles where the mechanism of injury was mixed. This decision was
10 taken in order to accurately reflect the settings the studies represent, where victims in conflict
11 zones are heterogenous and subject to a variety of combat related mechanisms. Studies were
12 omitted if they did not specify explosive mechanisms or include children.
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20 Children are defined as all humans under the age of eighteen years (as specified by the United
21 Nations Convention on the Rights of the Child)(4). The heterogeneity and arbitrary nature of
22 what defines a child is acknowledged, and studies often utilise individual definitions. Within
23 this review ages are defined thus: <1 year are infants, 1-8 are young children; 9-13 are older
24 children and 14-18 are adolescents.
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29 **Patient and public involvement statement:**

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Results

(Figure 1: Study selection)

Study selection of the 74 studies included in this review are shown in figure 1. Of these, 26 utilise trauma registries (table 1), 26 single centre hospital based case series (table 2), 8 use multi-centre hospital based case series (table 3), 13 use community surveillance (table 4) while 1 uses grey literature (table 5).

Table 1. The 26 studies utilising trauma registries

	Monitoring period	Location	Setting	Sample Size	Population	Exposure	Study	Effect investigated
Aharonson-Daniel et al (2003)(9)	2000-2001	Israel	Civilian	138	Paediatric (100%)	IEDs/Suicide IEDs (67%) GSW (25%) Other (8%)	Retrospective. National Trauma Registry	Injuries and mortality
Aharonson-Daniel et al (2006)(10)	2000-2004	Israel	Civilian	1155	Paediatric (8%) Adult (92%)	Suicide IEDs (100%)	Retrospective. National Trauma Registry	Injuries and mortality
Amir et al (2005)(11)	2000-2002	Israel	Civilian	148	Paediatric (100%)	IEDs/Shelling (66%) GSW (34%)	Retrospective. National Trauma Registry	Injuries and mortality
Bilukha et al (2015)(12)	2010-2013	Iraq	Civilian	2803	Paediatric (13%) Adult (87%)	IEDs (49%) Other/Unknown (51%)	Retrospective. Military Trauma Registry	Injuries and mortality
Bitterman et al (2016)(13)	2013	Israel	Military	84	Paediatric (100%)	IEDs/Shelling (67%) GSW (23%) Non-Combat (10%)	Retrospective. Military Trauma Registry	Injuries and mortality
Borgman et al (2012)(14)	2001-2011	Afghanistan Iraq	Military	128582	Paediatric (6%) Adult (94%)	Non-Combat (40%) IEDs/Shelling (38%) GSW (22%)	Retrospective. Military Trauma Registry	Injuries and mortality
Borgman et al (2015)(15)	2003-2011	Afghanistan Iraq	Military	549	Paediatric (100%)	Non-Combat (84%) IEDs/Shelling (11%) Other/Unknown (5%)	Retrospective. Military Trauma Registry	Injuries and mortality
Creamer et al (2009)(16)	2004-2007	Afghanistan Iraq	Military	2090	Paediatric (100%)	GSW (29%) IEDs/Shelling (24%) Other/Unknown (22%) Non-combat (25%)	Retrospective. Military Trauma Registry	Injuries and mortality
Dua et al (2013)(17)	2006-2008	Iraq	Military	25	Paediatric (100%)	IEDs/Shelling (72%) GSW (28%)	Retrospective. Military Trauma Registry	Injuries and mortality
Edwards et al (2012)(18)	2002-2012	Afghanistan Iraq	Military	4913	Paediatric (100%)	IEDs/Shelling (100%)	Retrospective. Military Trauma Registry	Injuries and mortality
Edwards et al (2014)(19)	2002-2012	Afghanistan Iraq	Military	6273	Paediatric (100%)	IEDs/Shelling (23%) GSW (16%) Other/Unknown (4%) Non-Combat (57%)	Retrospective. Military Trauma Registry	Injuries and mortality
Edwards et al (2014)(20)	2002-2010	Afghanistan Iraq	Military	4928	Paediatric (100%)	IEDs/Shelling (100%)	Retrospective. Military Trauma Registry	Injuries and mortality
Hillman et al (2016)(21)	2003-2014	Afghanistan Iraq	Military	27	Paediatric (100%)	IEDs /Shelling (59%) GSW (26%) Non-combat (15%)	Retrospective. Military Trauma Registry	Injuries and mortality
Jaffe et al (2010)(22)	2000-2005	Israel	Civilian	837	Paediatric (14%) Adult (86%)	IEDs (100%)	Retrospective. National Trauma Registry	Injuries and mortality
Khan et al (2015)(23)	2010-2011	Pakistan	Civilian	103	Paediatric (16%) Adult (84%)	IEDs (100%)	Retrospective National Trauma Registry	Injuries and mortality
Kluger et al (2004)(24)	2000-2003	Israel	Civilian	906	Paediatric (7%) Adult (93%)	IEDs (100%)	Retrospective. National Trauma Registry	Injuries and mortality
McKechnie et al (2014)(25)	2008-2012	Afghanistan	Military	766	Paediatric (100%)	IEDs/Shelling (51%) GSW (28%) Non-combat (21%)	Retrospective. Military Trauma Registry	Injuries and mortality
Naylor et al (2018)(26)	2007-2016	Afghanistan Iraq	Military	3439	Paediatric (100%)	IEDs/Shelling (38%) GSW (20%) Non-combat (11%) Other/Not specified (31%)	Retrospective. Military Trauma Registry	Injuries and mortality
Neff et al (2014)(27)	2001-2013	Afghanistan Iraq	Military	1113	Paediatric (100%)	IEDs/Shelling (56%) GSW (32%) Non-combat (12%)	Retrospective. Military Trauma Registry	Injuries and mortality
Patregnani et al (2012)(28)	2002-2009	Afghanistan Iraq	Military	744	Paediatric (100%)	IEDs/Shelling (43%) GSW (26%) Non-combat (31%)	Retrospective. Military Trauma Registry	Injuries and mortality
Quintana et al (1997)(29)	1996	USA	Civilian	66	Paediatric (100%)	IED (100%)	Retrospective. National Trauma Registry	Injuries and mortality
Schauer et al (2018)(30)	2007-2016	Afghanistan Iraq	Military	3388	Paediatric (100%)	IEDs/Shelling (43%) GSW (22%) Non-combat (35%)	Retrospective. Military Trauma Registry	Injuries and mortality
Smith et al (2014)(31)	2003-2011	Afghanistan Iraq	Military	813	Paediatric (6%) Adult (94%)	IEDs/Shelling (77%) GSW (23%)	Retrospective. Military Trauma Registry	Injuries and mortality
Villamaria et al (2014)(32)	2002-2011	Afghanistan Iraq	Military	155	Paediatric (100%)	IEDs/Shelling (58%) GSW (37%) Other/Not specified (5%)	Retrospective. Military Trauma Registry	Injuries and mortality
Walsman et al (2003)(33)	2000-2002	Israel	Civilian	160	Paediatric (100%)	IEDs (67%) GSW (25%) Other/Not specified (11%)	Retrospective. National Trauma Registry	Injuries and mortality
Woods et al (2012)(34)	2003-2009	Afghanistan Iraq	Military	176	Paediatric (100%)	IEDs/Shelling (59%) GSW (21%) Non-combat (20%)	Retrospective. Military Trauma Registry	Injuries and mortality

Table 2. The 26 studies utilising single centre hospital based case series

	Monitoring period	Location	Setting	Sample Size	Population	Exposure	Study	Effect investigated
Al-Worikat et al (2001)(35)	1988-2000	Jordan	Civilian	226	Paediatric (10%) Adult (90%)	Landmines (100%)	Retrospective. Single centre Hospital based case series	Long term sequelae
Arul et al (2012)(36)	2011	Afghanistan	Military	82	Paediatric (100%)	IEDs/Shelling (52%) GSW (11%) Non-combat (37%)	Retrospective. Single centre Hospital based case series	Injuries and mortality
Bajec et al (1993)(37)	1991	Kuwait	Civilian	152	Paediatric (12%) Adult (88%)	Landmines (100%)	Retrospective. Single centre Hospital based case series	Injuries and mortality
Beitler et al (2006)(38)	2002	Afghanistan	Military	204	Paediatric (28%) Adult (72%)	Non-combat (44%) IEDs/Shelling (36%) GSW (20%)	Retrospective. Single centre Hospital based case series	Injuries and mortality
Bertani et al (2015)(39)	2009-2013	Afghanistan	Military	89	Paediatric (100%)	IEDs/Shelling (79%) GSW (21%)	Retrospective. Single centre Hospital based case series	Injuries and mortality
Coppola et al (2006)(40)	2004-2005	Iraq	Military	85	Paediatric (100%)	IEDs/Shelling (29%) Non-combat (44%) Other/Unknown (27%)	Retrospective. Single centre Hospital based case series	Injuries and Mortality
Can et al (2009)(41)	2001-2008	Turkey	Civilian	23	Paediatric (100%)	Landmines (87%) UXO (13%)	Retrospective. Single centre Hospital based case series	Injuries and mortality
Chehab et al (2018)(42)	2009-2012	Afghanistan	Military	81	Paediatric (100%)	IEDs/Shelling (67%) GSW (21%) Stabbing (12%)	Retrospective. Single centre Hospital based case series	Injuries and mortality
Er et al (2017)(43)	2013-2014	Syria	Civilian	1591	Paediatric (18%) Adult (82%)	IEDs/Shelling (77%) GSW (7%) Other/Unknown (16%)	Retrospective. Single centre Hospital based case series	Injuries and Mortality
Fares et al (2013)(44)	2006-2011	Lebanon	Civilian	122	Paediatric (100%)	UXO (100%)	Retrospective. Single centre Hospital based case series	Long term sequelae
Fares et al (2014)(45)	2006-2013	Lebanon	Civilian	29	Paediatric (28%) Adult (72%)	UXO (100%)	Retrospective. Single centre Hospital based case series	Injuries and mortality
Gurney et al (2004)(46)	2003	Iraq	Military	78	Paediatric (100%)	IEDs/Shelling (7%) GSW (1%) Other/Not specified (9%) Non-Conflict (83%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Harris et al (2009)(5)	2008	Afghanistan	Military	15	Paediatric (100%)	IEDs/Shelling (87%) Other/Not specified (6%) Non-conflict (7%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Hinsley et al (2005)(47)	2003	Iraq	Military	79	Paediatric (10%) Adult (90%)	IEDs/Shelling (63%) GSW (37%)	Retrospective Single-centre Hospital based case series	Injuries and mortality
Hodalic et al (1999)(48)	1991-1992	Croatia	Military	1211	Paediatric (13%) Adult (87%)	IEDs/Shelling (95%) GSW (3%) Other/Not specified (2%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Inwald et al (2014)(49)	2011-2012	Afghanistan	Military	112	Paediatric (100%)	IEDs/Shelling (54%) GSW (29%) Non-conflict (17%)	Retrospective Single-centre Hospital based case series	Injuries and mortality
Jeevaratnam et al (2013)(50)	2010	Afghanistan	Military	88	Paediatric (35%) Adult (65%)	IEDs/Shelling (33%) Non-conflict (67%)	Retrospective Single-centre Hospital based case series	Injuries and mortality
Klimo et al (2010)(51)	2007-2009	Afghanistan	Military	43	Paediatric (100%)	IEDs/Shelling (67%) GSW (5%) Non-combat (28%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Matos et al (2008)(52)	2003-2004	Iraq	Military	1132	Paediatric (3%) Adult (97%)	IEDs/Shelling (64%) Non-combat (36%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
McGuigan et al (2007)(53)	2004	Iraq	Military	99	Paediatric (100%)	GSW (42%) IEDs/Shelling (35%) Other/Not specified (23%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Nordmann et al (2010)(54)	2008-2009	Afghanistan	Military	31	Paediatric (100%)	IEDs/Shelling (45%) GSW (32%) Non-combat (23%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Pannell et al (2015)(55)	2010-2011	Afghanistan	Military	263	Paediatric (100%)	IEDs/Shelling (42%) GSW (17%) Non-combat (41%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Pearce et al (2015)(56)	2011-2012	Afghanistan	Military	281	Paediatric (100%)	IEDs/Shelling (47%) GSW (13%) Non-combat (35%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Terzic et al (2001)(57)	1991-1995	Bosnia Croatia	Civilian	92	Paediatric (100%)	IEDs/Shelling/UXO (100%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Thompson et al (2017)(58)	2006-2013	Afghanistan	Military	295	Paediatric (100%)	IED (68%) UXO (4%) Other/Not specified (28%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Walker et al (2010)(59)	2006-2007	Afghanistan	Military	78	Paediatric (100%)	IEDs/Shelling (64%) GSW (37%) Other/Not specified (5%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Wilson et al (2013)(60)	2010-2011	Afghanistan	Military	41	Paediatric (100%)	IEDs/Shelling (47%) GSW (12%) Non-combat (42%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality

Table 3. The 8 studies utilising multi-centre hospital based case series

	Monitoring period	Location	Setting	Sample Size	Population	Exposure	Study	Effect investigated
Arafat et al (2017)(61)	2012-2013	Syria	Civilian	324	Paediatric (18%) Adult (82%)	IEDs/Shelling (57%) GSW (43%)	Retrospective. Multi-centre Hospital based case series	Injuries and mortality
Bendinelli et al (2009)(62)	2003-2006	Cambodia	Civilian	356	Paediatric (26%) Adult (74%)	Landmines (67%) UXO (33%)	Retrospective. Multi centre Hospital based case series	Injuries and mortality
Celikel et al (2014)(63)	2012	Syria	Civilian	186	Paediatric (22%) Adult (78%)	IEDs/Shelling (67%) GSW (26%) Other/Unknown (7%)	Retrospective. Multi-centre Hospital based mortuary case series	Mortality
Celikel et al (2015)(64)	2012-2014	Syria	Civilian	140	Paediatric (100%)	IEDs/Shelling (70%) GSW (14%) Other/Unknown (16%)	Retrospective. Multi-centre Hospital based mortuary case series	Mortality

Gataa et al (2011)(65)	2005-2006	Iraq	Civilian	551	Paediatric (20%) Adult (80%)	IEDs (82%) GSW (18%)	Retrospective. Multi-centre Hospital based case series	Injuries and mortality
Hanevik et al (2000)(66)	1991-1995	Eritrea	Civilian	248	Paediatric (63%) Adult (37%)	Landmines (100%)	Retrospective. Multi-centre Hospital based case series	Injuries and mortality
Mirza et al (2013)(67)	2007-2011	Pakistan	Civilian	1142	Paediatric (6%) Adult (94%)	IEDs (100%)	Retrospective Multi-centre Hospital based mortuary case series	Injuries and mortality
Spinella et al (2008)(68)	2001-2007	Afghanistan Iraq	Military	1305	Paediatric (100%)	Trauma (Unspecified) (100%)	Retrospective. Multi-centre Hospital based case series	Injuries and mortality

Table 4. The 13 studies utilising community surveillance

	Monitoring period	Location	Setting	Sample Size	Population	Exposure	Study	Effect investigated
Andersson et al (1995)(69)	1994-1995	Afghanistan Bosnia Cambodia Mozambique	Civilian	2100	Paediatric (100%)	Landmines (100%)	Retrospective. community surveillance	Socio-economic
Bilukha et al (2003)(70)	2001-2002	Afghanistan	Civilian	1636	Paediatric (46%) Adult (54%)	UXO (47%) Landmine (41%) Other/Unknown (12%)	Retrospective. Community Surveillance	Injuries and mortality
Bilukha et al (2007)(71)	1994-2005	Chechnya	Civilian	3021	Paediatric (30%) Adult (70%)	Landmines (41%) UXO (37%) Other/Unknown (22%)	Retrospective. Community Surveillance	Injuries and mortality
Bilukha et al (2008)(72)	2002-2006	Afghanistan	Civilian	5471	Paediatric (54%) Adult (46%)	UXO (50%) Landmines (42%) Other/Unknown (8%)	Retrospective. Community Surveillance	Injuries and mortality
Bilukha et al (2011)(73)	2006-2010	Nepal	Civilian	307	Paediatric (58%) Adult (42%)	IEDs (76%) Landmines (4%) Other/Unknown (20%)	Retrospective. Community Surveillance	Injuries and mortality
Bilukha et al (2013)(74)	2008-2011	Nepal	Civilian	437	Paediatric (14%) Adult (76%)	IEDs (69%) Other/Unknown (31%)	Retrospective. Community Surveillance	Injuries and mortality
Guerrero et al (2014)(75)	2013	USA	Civilian	11	Paediatric (100%)	IEDs (100%)	Prospective. Community Surveillance	Long term sequelae
Guha-Sapir et al (2018)(76)	2011-2016	Syria	Civilian	101453	Paediatric (17%) Adult (83%)	Shelling/Air bombardment (57%) Other/Not specified (43%)	Retrospective. Community Surveillance	Mortality
Hemmati et al (2015)(77)	1988-2013	Iran	Civilian	78	Paediatric (100%)	Landmines (100%)	Cross-section. Community surveillance	Long term sequelae
Kinra et al (2003)(78)	1991-2000	Bosnia and Herzegovina	Civilian	4064	Paediatric (14%) Adult (86%)	Landmines (100%)	Retrospective. Community Surveillance	Injuries and mortality
Mousavi et al (2015)(79)	2014	Iran	Civilian	78	Paediatric (100%)	Landmines (80%) UXO (20%)	Retrospective. Mixed-method community surveillance	Long-term sequelae/ Injuries and mortality
Pat-Horenczyk et al (2007)(80)	2006	Israel	Civilian	695	Paediatric (100%)	IEDs (100%)	Retrospective. Mixed-method community surveillance	Long term sequelae
Poor Zamany Nejat et al (2016)(81)	2015	Iran	Civilian	41	Paediatric (100%)	Landmines (100%)	Retrospective mixed-method community surveillance	Long term sequelae

Table 5. The 1 study utilising grey literature

	Monitoring period	Location	Setting	Sample Size	Population	Exposure	Study	Effect investigated
Guha-Sapir et al (2015)(82)	2011-2014	Syria	Civilian	78769	Paediatric (16%) Adult (84%)	IEDs/Shelling (75%) GSW (25%)	Grey-literature	Mortality

Demographics

Following the use of explosive weaponry by non-state actors against civilians, the most commonly injured paediatric cohort are males aged 10-18 years old(9,11,33), while children involved in conflict and ERW blast injuries were generally aged between 4-10 years old(18,59). Perpetrators target busy areas such as restaurants and nightclubs which older children and adolescents might frequent (10, 11,33), while cultural factors within LMICs in these social areas result in a predominantly male cohort (9,10,12,22–24,33,67,75,80). Similar gender finding are observed in children following conflict and ERW related injuries where all studies showed male predominance in victims, with over 70% male in three quarters of the studies (Figure 2).

(Figure 2. Gender differences in in casualties following blast)

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3 ERW contribute considerable morbidity and mortality both during and following conflict. As
4 seen in figure 3, children were more likely to be injured by UXO compared with adults, while
5 landmines affected a predominately adult cohort (35,37,41,62,69,70,72,73,78).
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11 (Figure 3. Percentage of Casualties (injuries and fatalities) by specific modalities)
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14 UXOs have been described as small, colourful and toy-like, promoting child interaction and
15 subsequent injury from handling, resulting in often fatal upper limb, head, neck or chest
16 injury(41,44,62,83,84). Due to the social nature of children, these interactions commonly occur
17 in groups, leading to multiple casualties in 45-63% of events involving children compared to
18 30-40% in adults(70,78,79).
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23 Occupation and education play a role in ERW injuries. It is common for children in LMICs,
24 particularly males, to assist their family with herding and farming as opposed to attending
25 school. This may affect the likelihood to exposure to ERWs through increased freedom to
26 roam where such devices are present(25,42,64,72). A lack of formal education impacts the
27 child's ability to read warning signs; only 6-22% of victims were aware ERWs were
28 present(27,80) and of these, only 0-11% had received ERW risk education(23,25,27,80).
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33 Children are particularly vulnerable to wide-area explosives such as aerial bombardment and
34 shelling, particularly in the primarily urbanised environments of modern conflicts. In the Syrian
35 Civil War, three quarters of wide-area explosives were used in civilian residential areas that
36 children frequent, with these mechanisms responsible for 82% of child deaths(76,82).
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41 The following section reviews what is known of mortality in children before reviewing injury
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45 **Mortality**

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48 Comparison of paediatric wartime mortality data is difficult as many studies do not differentiate
49 mechanism of injury. Edwards et al(85) study on 4,913 children between 2002-2010
50 presenting with blast injuries remains the single largest data set. The reported mortality rate
51 of 8% matches well with the mortality rates of 6-9% quoted in paediatric trauma deaths from
52 Iraq and Afghanistan, although these studies displayed all trauma mechanisms as opposed to
53 specifying blast trauma(14,16,20,25,36,40). Between 2006-2013, Thompson et al. (58) noted
54 a mortality rate over double of that quoted by Edwards et al. following paediatric blast injury
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3 in Afghanistan (18%). Operational tempo and the increasing use of IEDs have been
4 hypothesized to underlie these discrepancies in mortality(58).
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7 Age related variation in mortality has been described. Matos et al noted mortality was highest
8 at 24% in young children (5-8 year old)(52) while Schauer et al and Spinella et al found
9 greatest mortality in 0-4 years(30,68). Similarly, Borgman et al and Matos et al noted that
10 children <8 years old had increased trauma mortality compared to 8-16 year olds (10-18% vs
11 4-7%)(15,52), while Spinella et al noted a similar increase in mortality in young children (<6
12 year old) compared to 6-16 year olds (11% vs 4%)(68). Few studies directly compare adult
13 and paediatric mortality, and comparisons between studies are difficult due to methodological
14 differences. What is common is that mortality in children following combat related trauma is
15 considerably higher than that of paediatric non-combat trauma (2-3%)(86) and adult military
16 combat casualties (1-3%)(87,88).
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24 A wide range of paediatric mortality is reported following mine strikes, ranging from 4-
25 46%(41,44,62,69–74,83). Shuker et al(89) suggested that approximately half of paediatric
26 victims die within minutes of mine explosion, likely due to lacerations to the head, major blood
27 vessels or vital organs causing non-survivable injuries, in keeping with adult literature(87,88).
28 Time critical injuries following blasts may represent particular problems in LMIC's, where pre-
29 hospital evacuation chains may be protracted. Coupland(90) noted that in 1991, only 14% of
30 paediatric and adult ERW victims were admitted in under six hours, while the majority (58%)
31 were admitted between 6-24 hours and 28% presented after 24 hours. Even in recent conflicts,
32 Bitterman et al(13) found <10% of children presented within 1 hour, with over a third presenting
33 after 6 hours. Protracted evacuation of paediatric victims add to blast mortality, reinforced by
34 studies observing a 85-91% mortality of children either at scene or en-route to health
35 facilities(73,89).
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45 **Vascular injuries**

46 Penetrating injuries occur in 38-76% of blast-exposed children (9,10,14,16,33,36,37,55), with
47 incidence greater in older children aged 10-16 compared to 0-10 year olds (65-83% vs 47-
48 63%)(22,52). In keeping with penetrating injury patterns, vascular injury was observed in 3-
49 12% of children following blast trauma (9,32,33,37), considerably higher compared to non-
50 blast conflict trauma where vascular injury occurred in 0.6-1% of paediatric
51 victims(9,10,24,32,53).
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58 Vascular damage and subsequent haemorrhage following explosions have been identified as
59 a significant cause of childhood fatalities, ranging from the primary cause of death in 21-38%
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3 during the Syrian Civil War(63,64) to 63% following IED and suicide attacks in Pakistan(67),
4 while mortality rates following penetrating injuries in civilian settings are considerably lower
5 (5%)(32). Extremity trauma was most highly associated with vascular injuries, with the majority
6 of vascular injuries occurring in the lower limb (38-58%) followed by the upper limbs (25-
7 28%)(17,32). This is in keeping with adult data where 54% of injuries were sustained to the
8 extremities(87). Despite its high prevalence, extremity vascular wounds confer reduced risk of
9 death compared to vascular damage within the torso, attributed as the primary cause of death
10 in 71% of paediatric deaths and conferring a four-fold increased risk of death compared to
11 extremity vascular injuries(32).
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18 Data on vascular damage is clear: older children and adolescents sustain similar rates of
19 vascular injury to adults, particularly to the extremities, while mortality following penetrating
20 trauma is primarily the result of injuries to the vasculature within the torso.
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24 25 **Head injuries**

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27 The prevalence of head injuries following blasts are diverse, ranging from 6-54%
28 (10,11,40,42,43,47-49,53,13,16,18,32,33,36,38,39), while adult combat data ranges from 16-
29 29%(87). This variation is due to the heterogenous definitions of head injury described in these
30 studies, with few studies differentiating between superficial scalp wounds, blunt traumatic
31 brain injury (TBI) or penetrating TBI. Where head injuries were documented, TBI was recorded
32 in 21-62% of paediatric victims, of which 38-39% were defined as penetrating(33,45,48).
33 Unsurprisingly, papers noted over double the incidence of paediatric penetrating head injury
34 in blast trauma compared to mainly blunt civilian trauma (13% vs 6%), while the reverse was
35 true in closed head injuries, with half the incidence of closed head injuries in blast injuries
36 compared to civilian trauma (22% vs 44%)(9).
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44 Cerebral haemorrhage and direct cranial damage following blast have been attributed as a
45 leading cause of death in children, responsible for 46-71% of fatalities (36-38,43,101).
46 Creamer(38) noted penetrating wounds to the head accounted for 44% of child deaths in the
47 emergency department while open skull fractures with cerebral evisceration was documented
48 in 88% of paediatric fatalities following the 1995 Oklahoma City bombings(102). While
49 penetrating head injuries undoubtedly carry high mortality, Woods(34) noted that 8 children
50 survived to hospital discharge despite penetrating head injuries deemed initially unsurvivable,
51 suggesting such are not unequivocally fatal.
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57 Er et al(43) noted that children were more likely to be injured in the head compared to adults
58 (54% vs 40%) following aerial and shelling during the Syrian Civil War, while young children
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3 aged between 0-4 year old were more likely to undergo neurosurgical procedures compared
4 to other ages(20,51), 48% of which were craniectomies or craniotomies for penetrating brain
5 injury, mainly secondary to IED blasts(51). Suggested reasons for this increase may relate to
6 anatomical predispositions, particularly in infants, such as large head to body ratios in addition
7 to reduced skull rigidity(22) as well as the relatively shorter distance from the head to ground-
8 based ERW and IEDs compared to adults(18,22,62,84,89).
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14 There is a clear lack of studies investigating long term outcomes following blast- associated
15 head injuries. While significant cognitive, intellectual and functional sequelae arising from non-
16 blast TBI (nbTBI) have been described, controversy exists as to whether nbTBI is analogous
17 to blast-induced TBI(91), and the paucity of paediatric data means this comparison is even
18 more problematic.
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23 A unifying message is that head injuries are associated with high morbidity and mortality in
24 paediatric blast trauma, while the long term consequences remain largely unknown. Head
25 injuries are commonly penetrating compared to civilian practice, and increased operative
26 demand in infants and toddlers for neurosurgical procedures may stretch medical service
27 expertise.
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31 **Facial and ocular injuries**

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34 Blasts result in injury to the face in between 27-48% of paediatric victims, compared to 12%
35 resulting from GSW(11,18,49) and 10% in adults(87). Relative to other blast related injuries,
36 facial injuries in isolation are associated with reduced mortality(18). However, Gataa (65)
37 noted that of the patients presenting with facial injuries, 29% had concomitant eye injury, 22%
38 had TBI, while life-threatening facial bleeding occurred in 10% of patients. In addition to
39 physical sequelae, facial injuries are associated with functional and psychological disorders
40 stemming from stigmatisation of disfiguring injuries with implications for future social,
41 economic and marital prospects(65).
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49 Despite only comprising of 0.3% of the anterior body surface, the eye is sensitive to blast
50 injury, with ocular injuries in 4-28% of children following trauma related to combat or ERW
51 (13,16,36,38,39,42,45,53,79). In keeping with patterns of facial injury, an increased
52 prevalence of eye injury is associated with blast injuries compared to GSW (13% vs 3%)(11).
53 Landmines are often associated with multiple foreign bodies on the conjunctiva, cornea and
54 sclera, in addition to sight-threatening injuries such as enucleation or eye globe
55 perforation(41). Monocular enucleation was observed in 4%, while bilateral enucleation, and
56 hence blindness, was more common (14%)(41,79). When compared to adult victims of
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landmines and cluster bombs, children have more eye injuries (14% vs 8%)(78) as well as twice the prevalence of eye globe perforation (28% vs 14%)(43) and complete loss of vision (21 vs 10%)(62). Without adequate support, both monocular and bilateral vision loss may translate to developmental and educational deficiencies in the growing child.

Facial and eye injuries are frequent following exposure to blasts, and should raise suspicion of intracranial injury. Important are the social and education implications of these disfiguring injuries in the growing child.

Torso Injuries

Following blast injury, trauma to the torso is common, varying from 12-46% between studies (11,13,41,43,47-49,67,16-18,32,36,38-40) and peaking in 5-10 year olds(22,33). Er et al.'s (43) study on civilian paediatric injuries during the Syrian Civil War noted that the abdomen was less commonly injured compared to adults (12 vs 20%), while chest injury with accompanying lung contusion was present in 51% of children with torso injuries, compared to 35% in adults. Both chest and abdominal injuries from blast are typically classed as 'severe'(18). Abdominal injuries accounted for 18-19% of injury specific deaths following blast in the paediatric population, while chest injuries have been attributed to 8% of deaths in the ED(16). Explanations for this susceptibility to severe and life threatening torso injuries include a lack of body armour compared to adult combat victims and the observation that children have flexible rib cages allowing greater damage to underlying structures without rib fracture, contributing to the increase in lung contusion observed(32).

When organ specific injuries were examined, blast was most likely to cause open penetrating wounds of the bowel and intra-abdominal organs, affecting the small intestine in over a third (34%) and the liver, spleen or pancreas in 36%(16,54,61). Where internal organ damage was sustained, injury specific mortality almost doubled from 15 to 29%(63). These injuries were frequently contaminated due to bowel rupture, requiring multiple procedures and a high rate of antibiotic usage(57). The thinner abdominal walls, reduced intraabdominal fat and larger solid organs relative to the body cavity increases likelihood of visceral damage following penetrating trauma, while delayed signs of visceral damage support the role of repeated examination and radiological input, even in the absence of external damage.

In the context of total operative procedures performed, laparotomies comprised a significant component of total surgical workload, encompassing 12-23% of all paediatric procedures performed(25,58,92). Children were more likely to require laparotomies following combat trauma compared to paediatric non-combat, and primarily blunt, abdominal trauma (13 vs 2%).

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3 Children in combat zones were also twice as likely to undergo laparotomies compared to US
4 service personnel (12% vs 6%)(68). In addition to the high prevalence of abdominal injuries,
5 children frequently swallow air when frightened or in pain, resulting in gastric dilation. As well
6 as increasing vomiting risk, this may erroneously suggest abdominal injury(89) and lead to
7 laparotomy. Despite this, Arafat et al(61) noted that only 8% of laparotomies were negative,
8 supporting the role of explorative laparotomies in penetrating trauma following blasts.
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13 Compared to both adults and children in non-conflict settings, the blast injured child is more
14 likely to sustain injuries to the chest. While abdominal injuries are less frequent, they are more
15 likely to involve visceral damage and require operative management compared to adult
16 combat trauma.
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21 **Extremity injuries**

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24 Extremity injury is one of the defining features following blast related trauma. Extremity injuries
25 within conflict zones are observed in just under half of children (45%), its prevalence
26 increasing in blast injuries (69%)(49), with a retrospective study finding 100% of traumatic
27 amputations and 96% of bone injuries to hand and foot were secondary to blast injuries(39).
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31 Studies describe extreme variation in the prevalence of upper limb injuries following blasts,
32 ranging from 6-74% (13,25,40,41,47,48,58,67,69,29,32,33,35-39), with the greatest upper
33 limb injury reported following UXO and cluster munition strike(41,44). Compared to adult and
34 particularly following ERW blast, children were more likely to sustain upper limb injuries
35 (62,67,70-73) with a corresponding increase of 150-300% requiring operative amputation,
36 typically at the level of the finger (37,66,71,72). Traumatic amputation of the upper limb was
37 common and limited to the hands in 44-94% of children sustaining upper limb injuries(38,41),
38 while trans-radial and trans-humeral amputation was less frequent (14-34%)(25,48) but were
39 more likely to be bilateral(79). Arm fractures necessitating surgical fixation were observed in
40 45%(29), while upper limb vasculature was commonly disrupted(17,32,48).
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48 Similarly, prevalence of lower limb injuries shows variation between studies on blast affecting
49 25-86% of children(13,25,48,67,29,35-38,40,41,47), with landmine strikes particularly
50 associated with lower limb injury(35,37,41); 20-29% required operative amputations, normally
51 at the trans-tibial plane(37,38,79). Lower limb injuries were less common in children compared
52 to adults(62,70,72-74), with incidence lowest in 0-3 year olds(22), while increasing in
53 adolescents to mirror adults(62). Traumatic amputations were less frequent compared to the
54 upper limb, occurring in 14-35% of lower limb injuries(25,41,48).
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3 Landmines drive debris, footwear and clothing upward between planes of the soft tissues and
4 bone, leading to degloving injuries of the leg, perineum and lower abdominal viscera, as well
5 creating serious potential for soft tissue and bone infection in the remaining limb(84,90). While
6 large bony defects of the lower limb are problematic in children(93), reconstruction with limited
7 shortening (<2 cm) has been associated with good outcomes, with the capability for highly
8 active growth plates to remodel and compensate for this (39,94). However, 75% of new growth
9 occurs in the distal femur and tibia growth plates, with the distal limb most prone to explosive
10 disruption(84).

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17 The long term physical, psychosocial and financial repercussions of amputation must not be
18 underestimated. Physical complications are greatest following TA and below knee
19 amputations, and include anterior and varus bowing, heterotopic ossification and osseous
20 overgrowth requiring operative or prosthetic revision(95). Overgrowth is particularly
21 problematic in younger patients (under 12 years), with 15% of patients sustaining amputations
22 requiring re-vision of their stump. Protracted phantom limb sensation (PLS) and phantom limb
23 pain (PLP) is reported in over 50% of children following blast related amputation, similar to
24 that seen in adult literature following blasts(96), yet over five times higher than in children
25 requiring amputation following non-traumatic indications such as malignancy. Increased PLS
26 has been reported in lower limb amputations, while PLP was increased in upper limb
27 amputations (22,100). Social acceptance of the child amputee is culturally specific, with
28 stigmatisation in certain cultures negatively impacting the child's psychological, social and
29 educational status(97). While there is a paucity of outcome and long term costing studies in
30 LMICs, the financial burden of prolonged rehabilitation and repeated revision of prosthesis on
31 the children and host country's health system is likely to be considerable(97).

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41 Like adults involved in blast trauma, older and adolescents children are prone to extremity
42 injury, particularly of the upper limb, while infants and toddlers experience less extremity
43 injuries. Limb injury causes diverse complications in the growing child with increased
44 requirement for re-revision compared to adults.

45 46 47 48 49 **Burn injuries**

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52 Multiple retrospective studies have noted that the majority of burns in children result from
53 civilian mechanisms such as scalding, open fires and flash burns from household cooking
54 fuels (15,16,46,98,99), while approximately 9-12% is the result of high-order explosives
55 observed in combat blast modalities(46,99), less than observed in adult combat populations
56 (52%)(100). Unlike civilian mechanisms however, blast-induced burns rarely occur in isolation,
57 with multidimensional injuries playing a significant role in the child's prognosis(33,50,99).

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3 While post-mortem findings following the Syrian Civil War attributed only 0.5% of deaths being
4 secondary to burns(63), conflict-related burn victims had higher mortality compared to non-
5 conflict related burn victims (47% vs 3%)(98), and significantly greater than blast related burns
6 in adult military populations (5%)(100). Severe burns following blasts were sustained in 30%
7 of children, and fatal in 36-40%(18,40).
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12 Creamer(38) noted the median age of burn victims as 6 years old. At this young age, the
13 anatomical disproportionality of the child increases the total body surface area (TBSA),
14 resulting in significant burn surface area (BuSA). Thus, approximately half of paediatric burns
15 in conflict zones result in BuSA >15% (32,127), while 13% of children have BuSA exceeding
16 40%(127). A high BuSA exceeding 40% has been linked to myocardial damage and
17 hypotension, making hemodynamic management challenging, while complications including
18 nosocomial infection of the burn eschar and pneumonia are not uncommon(98). Within LMICs,
19 protein loss and weight based fluid resuscitation is complicated by malnourishment, while cold
20 fluids may accentuate hypothermia(46).
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28 In conflict related burns, the head and neck are most frequently affected, potentially leading
29 to thermal inhalation injuries(50,99). Thermal inhalation injuries in paediatric victims are
30 difficult to assess, and clues to inhalational injuries such as increased respiratory rate may be
31 incorrectly interpreted in the context of physiological age discrepancies. In addition the
32 paediatric subglottis represents the narrowest section of the upper airway, and deteriorates
33 rapidly from burn-induced laryngeal oedema, especially in the context of failed intubation
34 attempts(101) leading to rapid oxygen desaturation. Between 21-33% of children were
35 identified as having inhalational injuries requiring pre-emptive or immediate intubation to
36 protect the airways(50,53), similar to that seen in adult combat casualties (26%)(100). Of this
37 paediatric cohort with inhalational injuries, 39% died(50), significantly greater than in adult
38 populations (4%)(100).
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46 Prognosticating factors noted for burns include increased time to presentation, prolonged
47 hospital length of stay and requirement for critical care input(98). This relates to the resource-
48 intensive management of the paediatric burns patient. Like adults, hospital length of stay for
49 burns patients are 2-3 times that of the general paediatric population(36,99), while ICU
50 requirements are increased, particularly in burns secondary to blast injuries(98,99). Operative
51 demands of paediatric burn victims are significant. Children aged 6 months to 3 years were
52 between 4-14 times more likely than adults to require surgical input, reflecting the significant
53 burden of burns (39% of this cohort compared to 2-6% in adults(102)). While other conditions
54 may be treated by a single operation, burns often require serial procedures(102), with an
55 average 2 operations per patient. This creates a disproportionate operative volume in both
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adults and paediatric patients compared to other surgical emergencies(102). Burns induced by blast injuries require more escharotomies (27% vs 4% $P<0.001$) and fasciotomies (67% vs 30% $P=0.002$) when compared to civilian burn mechanisms(98).

Additionally, the requirement for post-operative support and rehabilitation add to the resource requirements. Children are rarely left without functional sequelae, with limited joint mobility and impaired tactile sensation presenting significant future challenges for rehabilitation(103), while high rates of psychological morbidity including suicidal ideation have been reported in adolescents(104). Under-resourcing psychological and functional rehabilitation will likely lead to high rates of morbidity and mortality(102). The degree to which these services are available within conflict zones and LMICs is uncertain. Ethical questions naturally arise when performing interventions where health systems are unlikely to address a child's long term needs. Examination of existing paediatric burn services within zones of interest and longer term follow up of paediatric blast burn patients are required to determine the problems and needs for this cohort.

Service provision

Relative to total admissions, paediatric victims affected by blasts constitute a disproportionately large resource burden on operative workload, as well as intensive care and hospital beds. Approximately 47-82% of paediatric blast victims require surgery(22,33,36,58,61), particularly adolescents(22). The requirement for multiple operative procedures were common in the paediatric cohort, especially in burn and orthopaedic surgery due to the requirement for surgical revision (34-80% of children required ≥ 2 procedures(16,18,36,38-40,42,54); 25% required ≥ 4 procedures)(16). Operative requirement was greatest in 9-14 year olds, requiring on average 5 procedures per patient, prolonged ICU and hospital stay, while 0-3 year olds required the least operative management(20). This study suggested the reduced requirement for operative input in 0-3 year olds may be due not only to the reduced burden of extremity injuries requiring repeated debridement, but potentially because the equipment was inappropriate for this young cohort. This is supported by observations that infants and young children aged 0-10 years old with an Injury Severity Score ≥ 15 were 4x less likely to go to surgery compared to adults, while adolescents (11-15 years) were 2x more likely to receive operative input(22).

Multidisciplinary surgical services were required in 80% of patients, with orthopaedic, plastic, general neurosurgical, ophthalmic and vascular surgeons often working in partnership(48). Debridement and primary skin closure represented the most common procedure, in 35-100% of studies(25,29,36-38,47,58,68), in keeping with shrapnel injuries leading to multiple and

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3 frequently contaminated superficial injuries(29,47). Children are likely to do well with thorough
4 debridement, with well perfused tissues allowing optimal healing and scar formation(39,94).
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7 Retrospective studies of US military medical treatment facilities (MTF) in Afghanistan have
8 found that while children comprised only 3-6% of their total admissions, this demographic
9 required approximately double the total bed spaces (7-11%)(14,19,53), and on average 3x the
10 length of stay (LOS) of coalition troops admitted over the same time period(14,68).
11 Approximately 40% of paediatric admissions required a LOS exceeding 7 days, while, in half
12 , the LOS exceeded 14 days(10,33). Spinella et al noted that while children aged 11-17 were
13 the greatest proportion of children occupying beds, <1 year old cohort had the longest
14 stay(68). This contrasts with other studies finding young children <8 years old had the shortest
15 LOS, while children(8-14 years old) had the longest(14,18).
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22 A similar burden is observed in the intensive care unit (ICU), with between 20-45% children
23 requiring ICU admission(5,30,33,36,43,50,53,54,61), the majority following explosive or
24 ballistic trauma. Children were often younger (0-10 years old)(22), with one recent study noting
25 children aged <1 year and 1-4 years most often requiring admission (53 & 66%
26 respectively)(30). Children under 8 required a ICU LOS over twice that of children aged >8
27 years (52). Harris et al(5) noted that despite representing only 12% of admissions, children
28 occupied on average 35% of ICU beds, with a brief surge in numbers resulting in 100%
29 occupancy from children, the majority requiring ventilatory and ionotropic support. This
30 specialised service was often provided by non-paediatric experts, which could result in 2
31 healthcare providers per paediatric patient(5). Ventilatory equipment is often age specific, and
32 although multiple examples of ingenuity and adaptation of adult equipment exist(5,54),
33 children may overwhelm the unprepared MTF.
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42 One of the key challenges is providing sustainable health services in the host country. MTFs
43 may be capable of delivering exceptional paediatric care in the acute phase following blasts,
44 but recovery from morbidity is dependent on long term rehabilitation(94) normally provided by
45 the host country. Not only can this place exceptional strain on local health authorities, but if
46 provisions are not available, the child is likely to undergo a protracted decline(5,94).
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51 Reasons for the high rate of admission and prolonged stay may be multifactorial. Admission
52 criteria for host nationals to a coalition MTF typically require threat to life, limb, or eyesight,
53 with resulting prolonged stay. Interestingly however, children with mild to moderate traumata
54 are three times more likely than adults to be admitted (22). This may reflect a lack of certainty
55 in initial assessment of injury severity from health practitioners unaccustomed to dealing with
56 children. Within conflict zones, rearwards evacuation of civilians is not always possible, and
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3 health interventions such as ventilatory support may not be sustainable by host countries
4 without deterioration in service standards, leading to prolonged admission until the child can
5 be safely moved(5).
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9 Following up recovery is a recurring theme when exploring long term challenges of blast
10 injuries in children(6). Children are a complex cohort to monitor. Geographical displacement,
11 particularly in the context of a conflict, increases the likelihood of this vulnerable cohort being
12 lost to follow-up. This can impact not only the child's rehabilitation and coordination with local
13 health authorities, but also cause difficulty in assessing long-term functional outcomes which
14 are needed to detect future health needs. Increasingly there is recognition of the need for
15 formalised trauma registries accessible in the host country, assisting the follow-up of this
16 vulnerable demographic(6,18,19,53).
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23 **Conclusion**

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26 Apart from their focus on paediatric blast, all the papers in this review have one thing in
27 common. Their research is based on those child patients injured by blast in conflict zones,
28 post-conflict zones and low resource environments. Most paediatric blast injury is inflicted in
29 these settings but is not exclusive to them. In Britain in May 2017, a bomb detonated at the
30 Manchester Arena killing 23 people and injuring 139, most of whom were children. The attack
31 placed a sudden and significant burden on medical services in the city, which had no
32 experience of paediatric blast injury in the 21st century, let alone on this kind of scale.
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38 Wherever in the world they live, and whatever the circumstances of the explosion, the social
39 and anatomical profile of children makes them uniquely vulnerable to one of the most complex
40 and demanding trauma conditions that any medical professional or system can treat. This
41 paper has characterised paediatric blast as a diverse injury pattern, which must be seen as
42 distinct from its adult equivalent. This pattern should be fully understood from point of
43 wounding through the post-operative and rehabilitation phases of treatment. This continuum
44 approach would enable both better long-term care of the patient, and improved support of
45 medical systems bearing the intense burden of that care.
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52 It remains to be seen whether the monitoring of the long term effects of paediatric blast injury
53 in well-resourced environments is any better than that in areas of instability. Monitoring of
54 patient outcomes should be integrated with the monitoring of treatment so that relevant
55 practice and skills can be continually assessed. It is urgent that the understanding of
56 paediatric blast injury is given focus and structure, not just for the likely significant patient
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3 cohort of the future but for those suffering today as blast injured children surviving into blast-
4 blighted adulthood, wherever they live in the world.
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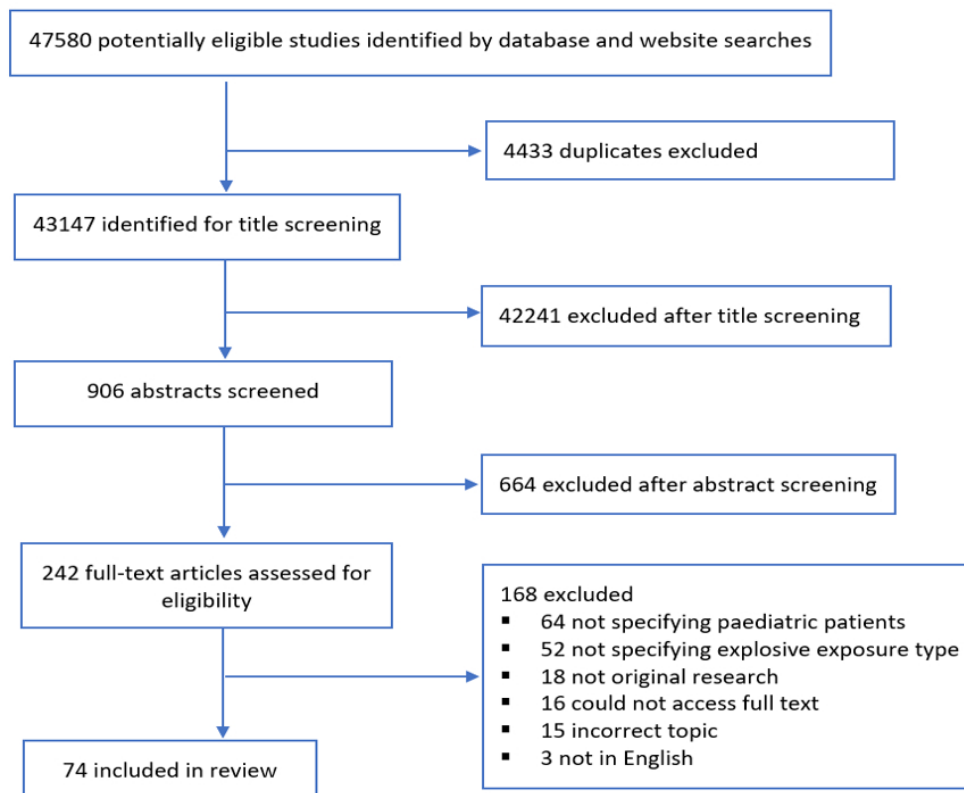
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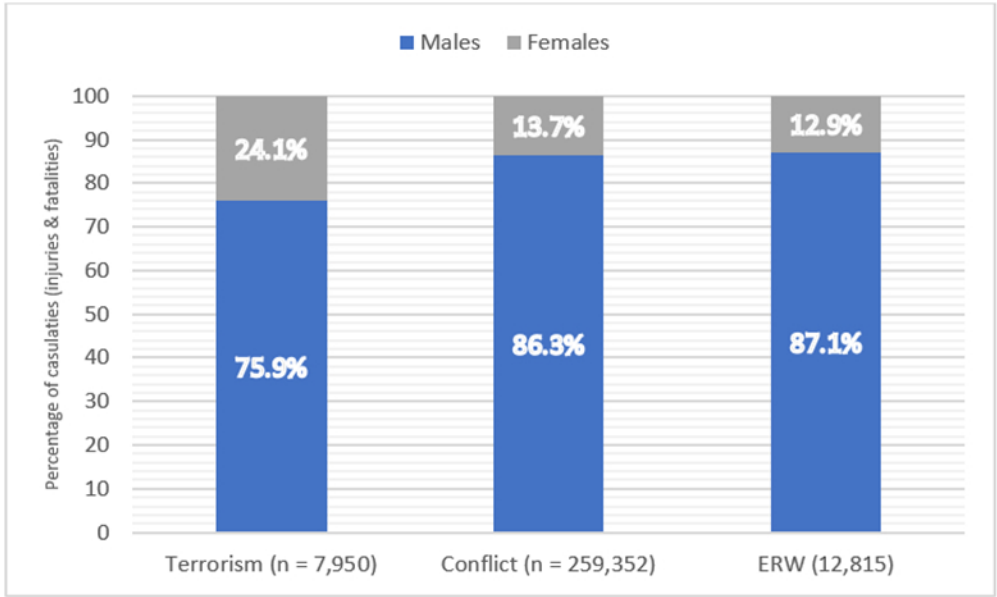
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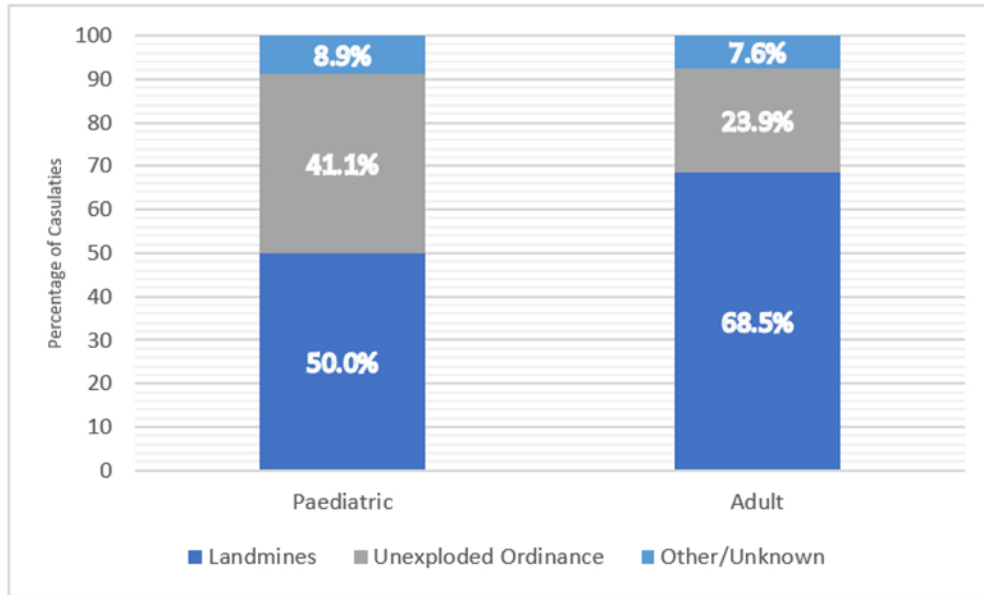
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Blast Injuries in Children: a mixed-methods narrative review.

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39 **Patient and public involvement statement:**

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41 **No patients or members of the public were involved in this review.**
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43

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45 **Contributorship Statement**

46
47 Professor Anthony Bull and Dr Emily Mayhew conceived the original analysis. Dr John
48 Hargrave undertook the literature review, with guidance on structure and inclusion of
49 sources by Dr Phil Pearce. Dr Anthony Bull advised on the bioengineering sections of the
50 review. Dr Pearce and Dr Taylor advised on the medical sections of the review. Dr Emily
51 Mayhew wrote the conclusion of the review. Dr Hargrave wrote the main body of the
52 review and selected the material for the tables and figures. Dr Hargrave designed and
53 completed the tables and figures. Dr Hargrave assembled the bibliography. All authors
54 contributed to the critical interpretation of the results, and approved the final draft of the
55 review.
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Key questions

What is already known on this topic?

- Approximately one in six children live in conflict zones, where exposure to blast injuries is not uncommon. Blast injuries have the potential to inflict significant mortality and morbidity upon the global paediatric population living in conflict zones.
- Describing the characteristics of injuries sustained by the paediatric population is essential in advancing local and global health policies. Despite this, common themes related to paediatric injury following to blasts are poorly described.

What this study adds?

- Paediatric victims are most likely to be male, with victims following conflict and explosive remnants of war (ERW) typically 4-10 years old. Of these victims, agricultural occupation and poor educational status is related to level of exposure.
- Head injuries are the leading cause of death in 46-71% of paediatric victims, and strongly associated with facial and ocular injuries conferring significant social and economic implications to the victims.
- Injuries to the extremities are seen in approximately half of children exposed to blast trauma, with upper limb injuries requiring between 1.5 to 3 times more operative intervention compared to adults. Functional repercussions of these injuries are significant, with 15% of traumatic amputations in the lower limb frequently requiring operative and prosthetic re-revision.
- An influx of paediatric patients can rapidly overwhelm health facilities, with between 47-82% of children requiring surgical intervention, of which 25% required over 4 procedures. Greater requirement for intensive care support in addition to prolonged inpatient and rehabilitative stays contributes to considerable service strain.

Abstract

Background and significance. Blast injuries arising from high explosive weaponry is common in conflict areas. While blast injury characteristics are well recognised in the adults, there is a lack of consensus as to whether these characteristics translate to the paediatric population. Understanding blast injury patterns in this cohort is essential for providing appropriate provision of services and care for this vulnerable cohort.

Methods. In this mixed-method review, original papers were screened for data pertaining to paediatric injuries following blasts. Information on demographics, morbidity and mortality and service requirements were evaluated. The papers were written and published in English from

1
2
3 a range of international specialists in the field. Patient and public involvement statement: No
4 patients or members of the public were involved in this review.
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7 **Results.** Children affected by blast injuries are predominantly male and their injuries arise
8 from explosive remnants of war, particularly unexploded ordinance. Blasts show increased
9 morbidity and mortality in younger children, while older children have injury patterns similar to
10 adults. Head and burn injuries represent a significant cause of mortality in young children,
11 while lower limb morbidity is reduced compared to adults. Children have a disproportionate
12 requirement for both operative and non-operative service resources, and provisions for this
13 burden are essential.
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19 **Conclusions.** Certain characteristics of paediatric injuries arising from blasts are distinct from
20 that of the adult cohort, while the intensive demands on services highlights the importance of
21 understanding the diverse injury patterns in order to optimise future service provisions in
22 caring for this the child blast survivor..
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Introduction

Approximately one in six children live in conflict zones, with the main global burden borne by citizens of low and middle income countries (LMICs)(1). Children enmeshed in conflict and post-conflict zones are frequently exposed to high-order explosives (HE), either through explosive remnants of war (ERW) such as landmines and unexploded ordinance (UXOs), military ordinance such as shelling and aerial bombardments or acts perpetrated by non-state actors such as improvised explosive devices (IEDs) and suicide bombing(2). HE can inflict unique and unusual injuries upon the child through the blast over-pressure wave (primary blast injury), energisation of materials causing fragmentation (secondary blast injury), bodily displacement or crush injuries (tertiary blast injuries) and through burns, inhalation, toxic or psychological trauma (quaternary blast injuries)(3).

Article 3.3 of the UN Convention on the Rights of the Child (UNCRC) states that medical care of the child be delivered and supervised by providers competent in that field(4). However, paediatric care in conflict zones is often delivered by personnel for whom experience of dealing with paediatric blast injuries is unusual(5). Primary studies increasingly recognise the complex patterns of injury sustained in the adult population following blast exposure(3), however there is a lack of consensus as to whether applying lessons learnt from the adult population translates appropriately into paediatric cohorts(6). Bree et al(7) argue that principles for life-saving interventions, such as prioritising catastrophic haemorrhage, airway, breathing and circulation are just as applicable in children as adults. Conversely Fendya et al(8) contend that directly applying adult trauma principles to the paediatric population neglects the social, anatomical, physiological and psychological differences between adults and children, affecting the validity of these inferences.

While primary studies have described injuries sustained by the blast injured child, no study has attempted to synthesise the data to identify recurrent characteristics in this vulnerable cohort. Understanding the characteristics of such injuries to the paediatric population will advance efforts to prevent, mitigate, and treat these injuries in domestic and deployed health systems(3). The aim of this review is to provide an overview of injury patterns and challenges in caring for the blast-injured child, in order to define future research needs for protection, mitigation, immediate medical treatment, and rehabilitation.

Methods

In this mixed-methods review, original peer-reviewed quantitative, qualitative and mixed-method observational studies, in addition to grey literature, were screened for data on

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3 explosive injuries in paediatric cohorts. By utilising all study designs, greater capture of
4 relevant literature was achieved, although this meant the data was unsuitable for a formal
5 systematic review. PubMed and Scopus (including Embase) were searched. Search terms
6 including “Paediatric” OR “Pediatric” OR “Child*” OR “Children” AND “Blast” OR “Explosi*” OR
7 “Explosion” were used to capture potential studies. Articles had to be written in English and
8 published before December 16, 2018. Studies involving adult as well as children were
9 included, in addition to articles where the mechanism of injury was mixed. This decision was
10 taken in order to accurately reflect the settings the studies represent, where victims in conflict
11 zones are heterogenous and subject to a variety of combat related mechanisms. Studies were
12 omitted if they did not specify explosive mechanisms or include children.
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20 Children are defined as all humans under the age of eighteen years (as specified by the United
21 Nations Convention on the Rights of the Child)(4). The heterogeneity and arbitrary nature of
22 what defines a child is acknowledged, and studies often utilise individual definitions. Within
23 this review ages are defined thus: <1 year are infants, 1-8 are young children; 9-13 are older
24 children and 14-18 are adolescents.
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29 **Patient and public involvement statement:**

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31 No patients or members of the public were involved in this review.
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Results

Figure 1: Study selection

Study selection of the 74 studies included in this review are shown in figure 1. Of these, 26 utilise trauma registries (table 1), 26 single centre hospital based case series (table 2), 8 use multi-centre hospital based case series (table 3), 13 use community surveillance (table 4) while 1 uses grey literature (table 5).

Table 1. The 26 studies utilising trauma registries

	Monitoring period	Location	Setting	Sample Size	Population	Exposure	Study	Effect investigated
Aharonson-Daniel et al (2003)(9)	2000-2001	Israel	Civilian	138	Paediatric (100%)	IEDs/Suicide IEDs (67%) GSW (25%) Other (8%)	Retrospective. National Trauma Registry	Injuries and mortality
Aharonson-Daniel et al (2006)(10)	2000-2004	Israel	Civilian	1155	Paediatric (8%) Adult (92%)	Suicide IEDs (100%)	Retrospective. National Trauma Registry	Injuries and mortality
Amir et al (2005)(11)	2000-2002	Israel	Civilian	148	Paediatric (100%)	IEDs/Shelling (66%) GSW (34%)	Retrospective. National Trauma Registry	Injuries and mortality
Bilukha et al (2015)(12)	2010-2013	Iraq	Civilian	2803	Paediatric (13%) Adult (87%)	IEDs (49%) Other/Unknown (51%)	Retrospective. Military Trauma Registry	Injuries and mortality
Bitterman et al (2016)(13)	2013	Israel	Military	84	Paediatric (100%)	IEDs/Shelling (67%) GSW (23%) Non-Combat (10%)	Retrospective. Military Trauma Registry	Injuries and mortality
Borgman et al (2012)(14)	2001-2011	Afghanistan Iraq	Military	128582	Paediatric (6%) Adult (94%)	Non-Combat (40%) IEDs/Shelling (38%) GSW (22%)	Retrospective. Military Trauma Registry	Injuries and mortality
Borgman et al (2015)(15)	2003-2011	Afghanistan Iraq	Military	549	Paediatric (100%)	Non-Combat (84%) IEDs/Shelling (11%) Other/Unknown (5%)	Retrospective. Military Trauma Registry	Injuries and mortality
Creamer et al (2009)(16)	2004-2007	Afghanistan Iraq	Military	2090	Paediatric (100%)	GSW (29%) IEDs/Shelling (24%) Other/Unknown (22%) Non-combat (25%)	Retrospective. Military Trauma Registry	Injuries and mortality
Dua et al (2013)(17)	2006-2008	Iraq	Military	25	Paediatric (100%)	IEDs/Shelling (72%) GSW (28%)	Retrospective. Military Trauma Registry	Injuries and mortality
Edwards et al (2012)(18)	2002-2012	Afghanistan Iraq	Military	4913	Paediatric (100%)	IEDs/Shelling (100%)	Retrospective. Military Trauma Registry	Injuries and mortality
Edwards et al (2014)(19)	2002-2012	Afghanistan Iraq	Military	6273	Paediatric (100%)	IEDs/Shelling (23%) GSW (16%) Other/Unknown (4%) Non-Combat (57%)	Retrospective. Military Trauma Registry	Injuries and mortality

Edwards et al (2014)(20)	2002-2010	Afghanistan Iraq	Military	4928	Paediatric (100%)	IEDs/Shelling (100%)	Retrospective. Military Trauma Registry	Injuries and mortality
Hillman et al (2016)(21)	2003-2014	Afghanistan Iraq	Military	27	Paediatric (100%)	IEDs /Shelling (59%) GSW (26%) Non-combat (15%)	Retrospective. Military Trauma Registry	Injuries and mortality
Jaffe et al (2010)(22)	2000-2005	Israel	Civilian	837	Paediatric (14%) Adult (86%)	IEDs (100%)	Retrospective. National Trauma Registry	Injuries and mortality
Khan et al (2015)(23)	2010-2011	Pakistan	Civilian	103	Paediatric (16%) Adult (84%)	IEDs (100%)	Retrospective National Trauma Registry	Injuries and mortality
Kluger et al (2004)(24)	2000-2003	Israel	Civilian	906	Paediatric (7%) Adult (93%)	IEDs (100%)	Retrospective. National Trauma Registry	Injuries and mortality
McKechnie et al (2014)(25)	2008-2012	Afghanistan	Military	766	Paediatric (100%)	IEDs/Shelling (51%) GSW (28%) Non-combat (21%)	Retrospective. Military Trauma Registry	Injuries and mortality
Naylor et al (2018)(26)	2007-2016	Afghanistan Iraq	Military	3439	Paediatric (100%)	IEDs/Shelling (38%) GSW (20%) Non-combat (11%) Other/Not specified (31%)	Retrospective. Military Trauma Registry	Injuries and mortality
Neff et al (2014)(27)	2001-2013	Afghanistan Iraq	Military	1113	Paediatric (100%)	IEDs/Shelling (56%) GSW (32%) Non-combat (12%)	Retrospective. Military Trauma Registry	Injuries and mortality
Patregnani et al (2012)(28)	2002-2009	Afghanistan Iraq	Military	744	Paediatric (100%)	IEDs/Shelling (43%) GSW (26%) Non-combat (31%)	Retrospective. Military Trauma Registry	Injuries and mortality
Quintana et al (1997)(29)	1996	USA	Civilian	66	Paediatric (100%)	IED (100%)	Retrospective. National Trauma Registry	Injuries and mortality
Schauer et al (2018)(30)	2007-2016	Afghanistan Iraq	Military	3388	Paediatric (100%)	IEDs/Shelling (43%) GSW (22%) Non-combat (35%)	Retrospective. Military Trauma Registry	Injuries and mortality
Smith et al (2014)(31)	2003-2011	Afghanistan Iraq	Military	813	Paediatric (6%) Adult (94%)	IEDs/Shelling (77%) GSW (23%)	Retrospective. Military Trauma Registry	Injuries and mortality
Villamaria et al (2014)(32)	2002-2011	Afghanistan Iraq	Military	155	Paediatric (100%)	IEDs/Shelling (58%) GSW (37%) Other/Not specified (5%)	Retrospective. Military Trauma Registry	Injuries and mortality
Waisman et al (2003)(33)	2000-2002	Israel	Civilian	160	Paediatric (100%)	IEDs (67%) GSW (25%) Other/Not specified (11%)	Retrospective. National Trauma Registry	Injuries and mortality
Woods et al (2012)(34)	2003-2009	Afghanistan Iraq	Military	176	Paediatric (100%)	IEDs/Shelling (59%) GSW (21%) Non-combat (20%)	Retrospective. Military Trauma Registry	Injuries and mortality

Table 2. The 26 studies utilising single centre hospital based case series

Monitoring period	Location	Setting	Sample Size	Population	Exposure	Study	Effect investigated
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1	Al-Worikat et al (2001)(35)	1988-2000	Jordan	Civilian	226	Paediatric (10%) Adult (90%)	Landmines (100%)	Retrospective. Single centre Hospital based case series	Long term sequelae
2									
3	Arul et al (2012)(36)	2011	Afghanistan	Military	82	Paediatric (100%)	IEDs/Shelling (52%) GSW (11%) Non-combat (37%)	Retrospective. Single centre Hospital based case series	Injuries and mortality
4									
5	Bajec et al (1993)(37)	1991	Kuwait	Civilian	152	Paediatric (12%) Adult (88%)	Landmines (100%)	Retrospective. Single centre Hospital based case series	Injuries and mortality
6									
7	Beitler et al (2006)(38)	2002	Afghanistan	Military	204	Paediatric (28%) Adult (72%)	Non-combat (44%) IEDs/Shelling (36%) GSW (20%)	Retrospective. Single centre Hospital based case series	Injuries and mortality
8									
9	Bertani et al (2015)(39)	2009-2013	Afghanistan	Military	89	Paediatric (100%)	IEDs/Shelling (79%) GSW (21%)	Retrospective. Single centre Hospital based case series	Injuries and mortality
10									
11	Coppola et al (2006)(40)	2004-2005	Iraq	Military	85	Paediatric (100%)	IEDs/Shelling (29%) Non-combat (44%) Other/Unknown (27%)	Retrospective. Single centre Hospital based case series	Injuries and Mortality
12									
13	Can et al (2009)(41)	2001-2008	Turkey	Civilian	23	Paediatric (100%)	Landmines (87%) UXO (13%)	Retrospective. Single centre Hospital based case series	Injuries and mortality
14									
15	Chehab et al (2018)(42)	2009-2012	Afghanistan	Military	81	Paediatric (100%)	IEDs/Shelling (67%) GSW (21%) Stabbing (12%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
16									
17	Er et al (2017)(43)	2013-2014	Syria	Civilian	1591	Paediatric (18%) Adult (82%)	IEDs/Shelling (77%) GSW (7%) Other/Unknown (16%)	Retrospective. Single-centre Hospital based case series	Injuries and Mortality
18									
19	Fares et al (2013)(44)	2006-2011	Lebanon	Civilian	122	Paediatric (100%)	UXO (100%)	Retrospective. Single centre Hospital based case series	Long term sequelae
20									
21	Fares et al (2014)(45)	2006-2013	Lebanon	Civilian	29	Paediatric (28%) Adult (72%)	UXO (100%)	Retrospective. Single centre Hospital based case series	Injuries and mortality
22									
23	Gurney et al (2004)(46)	2003	Iraq	Military	78	Paediatric (100%)	IEDs/Shelling (7%) GSW (1%) Other/Not specified (9%) Non-Conflict (83%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
24									
25	Harris et al (2009)(5)	2008	Afghanistan	Military	15	Paediatric (100%)	IEDs/Shelling (87%) Other/Not specified (6%) Non-conflict (7%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
26									
27	Hinsley et al (2005)(47)	2003	Iraq	Military	79	Paediatric (10%) Adult (90%)	IEDs/Shelling (63%) GSW (37%)	Retrospective Single-centre Hospital based case series	Injuries and mortality
28									
29	Hodalic et al (1999)(48)	1991-1992	Croatia	Military	1211	Paediatric (13%) Adult (87%)	IEDs/Shelling (95%) GSW (3%) Other/Not specified (2%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
30									
31	Inwald et al (2014)(49)	2011-2012	Afghanistan	Military	112	Paediatric (100%)	IEDs/Shelling (54%) GSW (29%) Non-conflict (17%)	Retrospective Single-centre Hospital based case series	Injuries and mortality
32									
33	Jeevaratnam et al (2013)(50)	2010	Afghanistan	Military	88	Paediatric (35%) Adult (65%)	IEDs/Shelling (33%) Non-conflict (67%)	Retrospective Single-centre Hospital based case series	Injuries and mortality
34									
35	Klumo et al (2010)(51)	2007-2009	Afghanistan	Military	43	Paediatric (100%)	IEDs/Shelling (67%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
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						GSW (5%) Non-combat (28%)		
Matos et al (2008)(52)	2003-2004	Iraq	Military	1132	Paediatric (3%) Adult (97%)	IEDs/Shelling (64%) Non-combat (36%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
McGuigan et al (2007)(53)	2004	Iraq	Military	99	Paediatric (100%)	GSW (42%) IEDs/Shelling (35%) Other/Not specified (23%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Nordmann et al (2010)(54)	2008-2009	Afghanistan	Military	31	Paediatric (100%)	IEDs/Shelling (45%) GSW (32%) Non-combat (23%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Pannell et al (2015)(55)	2010-2011	Afghanistan	Military	263	Paediatric (100%)	IEDs/Shelling (42%) GSW (17%) Non-combat (41%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Pearce et al (2015)(56)	2011-2012	Afghanistan	Military	281	Paediatric (100%)	IEDs/Shelling (47%) GSW (13%) Non-combat (35%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Terzic et al (2001)(57)	1991-1995	Bosnia Croatia	Civilian	92	Paediatric (100%)	IEDs/Shelling/UXO (100%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Thompson et al (2017)(58)	2006-2013	Afghanistan	Military	295	Paediatric (100%)	IED (68%) UXO (4%) Other/Not specified (28%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Walker et al (2010)(59)	2006-2007	Afghanistan	Military	78	Paediatric (100%)	IEDs/Shelling (64%) GSW (37%) Other/Not specified (5%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Wilson et al (2013)(60)	2010-2011	Afghanistan	Military	41	Paediatric (100%)	IEDs/Shelling (47%) GSW (12%) Non-combat (42%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality

Table 3. The 8 studies utilising multi-centre hospital based case series

	Monitoring period	Location	Setting	Sample Size	Population	Exposure	Study	Effect investigated
Arafat et al (2017)(61)	2012-2013	Syria	Civilian	324	Paediatric (18%) Adult (82%)	IEDs/Shelling (57%) GSW (43%)	Retrospective. Multi-centre Hospital based case series	Injuries and mortality
Bendinelli et al (2009)(62)	2003-2006	Cambodia	Civilian	356	Paediatric (26%) Adult (74%)	Landmines (67%) UXO (33%)	Retrospective. Multi-centre Hospital based case series	Injuries and mortality
Celikel et al (2014)(63)	2012	Syria	Civilian	186	Paediatric (22%) Adult (78%)	IEDs/Shelling (67%) GSW (26%) Other/Unknown (7%)	Retrospective. Multi-centre Hospital based mortuary case series	Mortality
Celikel et al (2015)(64)	2012-2014	Syria	Civilian	140	Paediatric (100%)	IEDs/Shelling (70%) GSW (14%) Other/Unknown (16%)	Retrospective. Multi-centre Hospital based mortuary case series	Mortality
Gataa et al (2011)(65)	2005-2006	Iraq	Civilian	551	Paediatric (20%) Adult (80%)	IEDs (82%) GSW (18%)	Retrospective. Multi-centre Hospital based case series	Injuries and mortality

Hanevik et al (2000)(66)	1991-1995	Eritrea	Civilian	248	Paediatric (63%) Adult (37%)	Landmines (100%)	Retrospective. Multi-centre Hospital based case series	Injuries and mortality
Mirza et al (2013)(67)	2007-2011	Pakistan	Civilian	1142	Paediatric (6%) Adult (94%)	IEDs (100%)	Retrospective Multi-centre Hospital based mortuary case series	Injuries and mortality
Spinella et al 2008(68)	2001-2007	Afghanistan Iraq	Military	1305	Paediatric (100%)	Trauma (Unspecified) (100%)	Retrospective. Multi-centre Hospital based case series	Injuries and mortality

Table 4. The 13 studies utilising community surveillance

	Monitoring period	Location	Setting	Sample Size	Population	Exposure	Study	Effect investigated
Andersson et al (1995)(69)	1994-1995	Afghanistan Bosnia Cambodia Mozambique	Civilian	2100	Paediatric (100%)	Landmines (100%)	Retrospective. community surveillance	Socio-economic
Bilukha et al (2003)(70)	2001-2002	Afghanistan	Civilian	1636	Paediatric (46%) Adult (54%)	UXO (47%) Landmine (41%) Other/Unknown (12%)	Retrospective. Community Surveillance	Injuries and mortality
Bilukha et al (2007)(71)	1994-2005	Chechnya	Civilian	3021	Paediatric (30%) Adult (70%)	Landmines (41%) UXO (37%) Other/Unknown (22%)	Retrospective. Community Surveillance	Injuries and mortality
Bilukha et al (2008)(72)	2002-2006	Afghanistan	Civilian	5471	Paediatric (54%) Adult (46%)	UXO (50%) Landmines (42%) Other/Unknown (8%)	Retrospective. Community Surveillance	Injuries and mortality
Bilukha et al (2011)(73)	2006-2010	Nepal	Civilian	307	Paediatric (58%) Adult (42%)	IEDs (76%) Landmines (4%) Other/Unknown (20%)	Retrospective. Community Surveillance	Injuries and mortality
Bilukha et al (2013)(74)	2008-2011	Nepal	Civilian	437	Paediatric (14%) Adult (76%)	IEDs (69%) Other/Unknown (31%)	Retrospective. Community Surveillance	Injuries and mortality
Guerrero et al (2014)(75)	2013	USA	Civilian	11	Paediatric (100%)	IEDs (100%)	Prospective. Community Surveillance	Long term sequelae
Guha-Sapir et al (2018)(76)	2011-2016	Syria	Civilian	101453	Paediatric (17%) Adult (83%)	Shelling/Air bombardment (57%) Other/Not specified (43%)	Retrospective. Community Surveillance	Mortality
Hemmati et al (2015)(77)	1988-2013	Iran	Civilian	78	Paediatric (100%)	Landmines (100%)	Cross-section. Community surveillance	Long term sequelae
Kinra et al (2003)(78)	1991-2000	Bosnia and Herzegovina	Civilian	4064	Paediatric (14%) Adult (86%)	Landmines (100%)	Retrospective. Community Surveillance	Injuries and mortality
Mousavi et al (2015)(79)	2014	Iran	Civilian	78	Paediatric (100%)	Landmines (80%) UXO (20%)	Retrospective. Mixed-method community surveillance	Long-term sequelae/ Injuries and mortality
Pat-Horenczyk et al (2007)(80)	2006	Israel	Civilian	695	Paediatric (100%)	IEDs (100%)	Retrospective. Mixed-method community surveillance	Long term sequelae
Poor Zamany Nejat et al (2016)(81)	2015	Iran	Civilian	41	Paediatric (100%)	Landmines (100%)	Retrospective mixed-method community surveillance	Long term sequelae

Table 5. The 1 study utilising grey literature

	Monitoring period	Location	Setting	Sample Size	Population	Exposure	Study	Effect investigated
Guha-Sapir et al (2015)(82)	2011-2014	Syria	Civilian	78769	Paediatric (16%) Adult (84%)	IEDs/Shelling (75%) GSW (25%)	Grey-literature	Mortality

Demographics

Following the use of explosive weaponry by non-state actors against civilians, the most commonly injured paediatric cohort are males aged 10-18 years old(9,11,33), while children involved in conflict and ERW blast injuries were generally aged between 4-10 years old(18,59). Perpetrators target busy areas such as restaurants and nightclubs which older children and adolescents might frequent (10,11,33), while cultural factors within LMICs in these social areas result in a predominantly male cohort (9,10,12,22–24,33,67,75,80). Similar gender finding are observed in children following conflict and ERW related injuries where all studies showed male predominance in victims, with over 70% male in three quarters of the studies (Figure 2).

Figure 2. Gender differences in in casualties following blast

ERW contribute considerable morbidity and mortality both during and following conflict. As seen in figure 3, children were more likely to be injured by UXO compared with adults, while landmines affected a predominately adult cohort (35,37,41,62,69,70,72,73,78). It should be noted that statistics on pre-hospital mortality for children in conflict settings is generally an underestimation due to the difficulties in reporting and monitoring. Many explosive weapons observation groups do not or are unable to distinguish between adults and children in their reporting.

Figure 3. Percentage of Casualties (injuries and fatalities) by specific modalities

UXOs have been described as small, colourful and toy-like, promoting child interaction and subsequent injury from handling, resulting in often fatal upper limb, head, neck or chest injury(41,44,62,83,84). Due to the social nature of children, these interactions commonly occur in groups, leading to multiple casualties in 45-63% of events involving children compared to 30-40% in adults(70,78,79).

Occupation and education play a role in ERW injuries. It is common for children in LMICs, particularly males, to assist their family with herding and farming as opposed to attending school. This may affect the likelihood to exposure to ERWs through increased freedom to roam where such devices are present(25,42,64,72). A lack of formal education impacts the child's ability to read warning signs; only 6-22% of victims were aware ERWs were present(27,80) and of these, only 0-11% had received ERW risk education(23,25,27,80).

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3 Children are particularly vulnerable to wide-area explosives such as aerial bombardment and
4 shelling, particularly in the primarily urbanised environments of modern conflicts. In the Syrian
5 Civil War, three quarters of wide-area explosives were used in civilian residential areas that
6 children frequent, with these mechanisms responsible for 82% of child deaths(76,82).
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10 The following section reviews what is known of mortality in children before reviewing injury
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14 **Mortality**

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18 Comparison of paediatric wartime mortality data is difficult as many studies do not differentiate
19 mechanism of injury. Edwards et al(85) study on 4,913 children between 2002-2010
20 presenting with blast injuries remains the single largest data set. The reported mortality rate
21 of 8% matches well with the mortality rates of 6-9% quoted in paediatric trauma deaths from
22 Iraq and Afghanistan, although these studies displayed all trauma mechanisms as opposed to
23 specifying blast trauma(14,16,20,25,36,40). Between 2006-2013, Thompson et al. (58) noted
24 a mortality rate over double of that quoted by Edwards et al. following paediatric blast injury
25 in Afghanistan (18%). Operational tempo and the increasing use of IEDs have been
26 hypothesized to underlie these discrepancies in mortality(58).
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33 Age related variation in mortality has been described. Matos et al noted mortality was highest
34 at 24% in young children (5-8 year old)(52) while Schauer et al and Spinella et al found
35 greatest mortality in 0-4 years(30,68). Similarly, Borgman et al and Matos et al noted that
36 children <8 years old had increased trauma mortality compared to 8-16 year olds (10-18% vs
37 4-7%)(15,52), while Spinella et al noted a similar increase in mortality in young children (<6
38 year old) compared to 6-16 year olds (11% vs 4%)(68). Few studies directly compare adult
39 and paediatric mortality, and comparisons between studies are difficult due to methodological
40 differences. What is common is that mortality in children following combat related trauma is
41 considerably higher than that of paediatric non-combat trauma (2-3%)(86) and adult military
42 combat casualties (1-3%)(87,88).
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50 A wide range of paediatric mortality is reported following mine strikes, ranging from 4-
51 46%(41,44,62,69-74,83). Shuker et al(89) suggested that approximately half of paediatric
52 victims die within minutes of mine explosion, likely due to penetrating head injury, and
53 catastrophic haemorrhage causing non-survivable injuries, in keeping with adult
54 literature(87,88). Time critical injuries following blasts may represent particular problems in
55 LMIC's, where pre-hospital evacuation chains may be protracted. Coupland(90) noted that in
56 1991, only 14% of paediatric and adult ERW victims were admitted in under six hours, while
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3 the majority (58%) were admitted between 6-24 hours and 28% presented after 24 hours.
4 Even in recent conflicts, Bitterman et al(13) found <10% of children presented within 1 hour,
5 with over a third presenting after 6 hours. Protracted evacuation of paediatric victims add to
6 blast mortality, reinforced by studies observing a 85-91% mortality of children either at scene
7 or en-route to health facilities(73,89).
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11 **Vascular injuries**

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13 Penetrating injuries occur in 38-76% of blast-exposed children (9,10,14,16,33,36,37,55), with
14 incidence greater in older children aged 10-16 compared to 0-10 year olds (65-83% vs 47-
15 63%)(22,52). In keeping with penetrating injury patterns, vascular injury was observed in 3-
16 12% of children following blast trauma (9,32,33,37), considerably higher compared to non-
17 blast conflict trauma where vascular injury occurred in 0.6-1% of paediatric
18 victims(9,10,24,32,53).
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26 Vascular damage and subsequent haemorrhage following explosions have been identified as
27 a significant cause of childhood fatalities, ranging from the primary cause of death in 21-38%
28 during the Syrian Civil War(63,64) to 63% following IED and suicide attacks in Pakistan(67),
29 while mortality rates following penetrating injuries in civilian settings are considerably lower
30 (5%)(32). Extremity trauma was most highly associated with vascular injuries, with the majority
31 of vascular injuries occurring in the lower limb (38-58%) followed by the upper limbs (25-
32 28%)(17,32). This is in keeping with adult data where 54% of injuries were sustained to the
33 extremities(87). Despite its high prevalence, extremity vascular wounds confer reduced risk of
34 death compared to vascular damage within the torso, attributed as the primary cause of death
35 in 71% of paediatric deaths and conferring a four-fold increased risk of death compared to
36 extremity vascular injuries(32).
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44 Data on vascular damage is clear: older children and adolescents sustain similar rates of
45 vascular injury to adults, particularly to the extremities, while mortality following penetrating
46 trauma is primarily the result of injuries to the vasculature within the torso.
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50 **Head injuries**

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52 The prevalence of head injuries following blasts are diverse, ranging from 6-54%
53 (10,11,40,42,43,47-49,53,13,16,18,32,33,36,38,39), while adult combat data ranges from 16-
54 29%(87). This variation is due to the heterogenous definitions of head injury described in these
55 studies, with few studies differentiating between superficial scalp wounds, blunt traumatic
56 brain injury (TBI) or penetrating TBI. Where head injuries were documented, TBI was recorded
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3 in 21-62% of paediatric victims, of which 38-39% were defined as penetrating(33,45,48).
4 Unsurprisingly, papers noted over double the incidence of paediatric penetrating head injury
5 in blast trauma compared to mainly blunt civilian trauma (13% vs 6%), while the reverse was
6 true in closed head injuries, with half the incidence of closed head injuries in blast injuries
7 compared to civilian trauma (22% vs 44%)(9).
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12 Cerebral haemorrhage and direct cranial damage following blast have been attributed as a
13 leading cause of death in children, responsible for 46-71% of fatalities (36–38,43,101).
14 Creamer(38) noted penetrating wounds to the head accounted for 44% of child deaths in the
15 emergency department while open skull fractures with cerebral evisceration was documented
16 in 88% of paediatric fatalities following the 1995 Oklahoma City bombings(102). While
17 penetrating head injuries undoubtedly carry high mortality, Woods(34) noted that 8 children
18 survived to hospital discharge despite penetrating head injuries deemed initially unsurvivable,
19 suggesting such are not unequivocally fatal.
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26 Er et al(43) noted that children were more likely to be injured in the head compared to adults
27 (54% vs 40%) following aerial and shelling during the Syrian Civil War, while young children
28 aged between 0-4 year old were more likely to undergo neurosurgical procedures compared
29 to other ages(20,51), 48% of which were craniectomies or craniotomies for penetrating brain
30 injury, mainly secondary to IED blasts(51). Suggested reasons for this increase may relate to
31 anatomical predispositions, particularly in infants, such as large head to body ratios in addition
32 to reduced skull rigidity(22) as well as the relatively shorter distance from the head to ground-
33 based ERW and IEDs compared to adults(18,22,62,84,89).
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40 There is a clear lack of studies investigating long term outcomes following blast- associated
41 head injuries. While significant cognitive, intellectual and functional sequelae arising from non-
42 blast TBI (nbTBI) have been described, controversy exists as to whether nbTBI is analogous
43 to blast-induced TBI(91), and the paucity of paediatric data means this comparison is even
44 more problematic.
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49 A unifying message is that head injuries are associated with high morbidity and mortality in
50 paediatric blast trauma, while the long term consequences remain largely unknown. Head
51 injuries are commonly penetrating compared to civilian practice, and increased operative
52 demand in infants and toddlers for neurosurgical procedures may stretch medical service
53 expertise.
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57 **Facial and ocular injuries**

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3 Blasts result in injury to the face in between 27-48% of paediatric victims, compared to 12%
4 resulting from GSW(11,18,49) and 10% in adults(87). Relative to other blast related injuries,
5 facial injuries in isolation are associated with reduced mortality(18). However, Gataa (65)
6 noted that of the patients presenting with facial injuries, 29% had concomitant eye injury, 22%
7 had TBI, while life-threatening facial bleeding occurred in 10% of patients. In addition to
8 physical sequelae, facial injuries are associated with functional and psychological disorders
9 stemming from stigmatisation of disfiguring injuries with implications for future social,
10 economic and marital prospects(65).
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17 Despite only comprising of 0.3% of the anterior body surface, the eye is sensitive to blast
18 injury, with ocular injuries in 4-28% of children following trauma related to combat or ERW
19 (13,16,36,38,39,42,45,53,79). In keeping with patterns of facial injury, an increased
20 prevalence of eye injury is associated with blast injuries compared to GSW (13% vs 3%)(11).
21 Landmines are often associated with multiple foreign bodies on the conjunctiva, cornea and
22 sclera, in addition to sight-threatening injuries such as enucleation or eye globe
23 perforation(41). Monocular enucleation was observed in 4%, while bilateral enucleation, and
24 hence blindness, was more common (14%)(41,79). When compared to adult victims of
25 landmines and cluster bombs, children have more eye injuries (14% vs 8%)(78) as well as
26 twice the prevalence of eye globe perforation (28% vs 14%)(43) and complete loss of vision
27 (21 vs 10%)(62). Without adequate support, both monocular and bilateral vision loss may
28 translate to developmental and educational deficiencies in the growing child.
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37 Facial and eye injuries are frequent following exposure to blasts, and should raise suspicion
38 of intracranial injury. Important are the social and education implications of these disfiguring
39 injuries in the growing child.
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42 **Torso Injuries**

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45 Following blast injury, trauma to the torso is common, varying from 12-46% between studies
46 (11,13,41,43,47-49,67,16-18,32,36,38-40) and peaking in 5-10 year olds(22,33). Er et al.'s
47 (43) study on civilian paediatric injuries during the Syrian Civil War noted that the abdomen
48 was less commonly injured compared to adults (12 vs 20%), while chest injury with
49 accompanying lung contusion was present in 51% of children with torso injuries, compared to
50 35% in adults. Both chest and abdominal injuries from blast are typically classed as
51 'severe'(18). Abdominal injuries accounted for 18-19% of injury specific deaths following blast
52 in the paediatric population, while chest injuries have been attributed to 8% of deaths in the
53 ED(16). Explanations for this susceptibility to severe and life threatening torso injuries include
54 a lack of body armour compared to adult combat victims and the observation that children
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3 have flexible rib cages allowing greater damage to underlying structures without rib fracture,
4 contributing to the increase in lung contusion observed(32).
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7 When organ specific injuries were examined, blast was most likely to cause open penetrating
8 wounds of the bowel and intra-abdominal organs, affecting the small intestine in over a third
9 (34%) and the liver, spleen or pancreas in 36%(16,54,61). Where internal organ damage was
10 sustained, injury specific mortality almost doubled from 15 to 29%(63). These injuries were
11 frequently contaminated due to bowel rupture, requiring multiple procedures and a high rate
12 of antibiotic usage(57). The thinner abdominal walls, reduced intraabdominal fat and larger
13 solid organs relative to the body cavity increases likelihood of visceral damage following
14 penetrating trauma, while delayed signs of visceral damage support the role of repeated
15 examination and radiological input, even in the absence of external damage.
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22 In the context of total operative procedures performed, laparotomies comprised a significant
23 component of total surgical workload, encompassing 12-23% of all paediatric procedures
24 performed(25,58,92). Children were more likely to require laparotomies following combat
25 trauma compared to paediatric non-combat, and primarily blunt, abdominal trauma (13 vs 2%).
26 Children in combat zones were also twice as likely to undergo laparotomies compared to US
27 service personnel (12% vs 6%)(68). In addition to the high prevalence of abdominal injuries,
28 children frequently swallow air when frightened or in pain, resulting in gastric dilation. As well
29 as increasing vomiting risk, this may erroneously suggest abdominal injury(89) and lead to
30 laparotomy. Despite this, Arafat et al(61) noted that only 8% of laparotomies were negative,
31 supporting the role of explorative laparotomies in penetrating trauma following blasts.
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39 Compared to both adults and children in non-conflict settings, the blast injured child is more
40 likely to sustain injuries to the chest. While abdominal injuries are less frequent, they are more
41 likely to involve visceral damage and require operative management compared to adult
42 combat trauma.
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46 47 **Extremity injuries**

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49 Extremity injury is one of the defining features following blast related trauma. Extremity injuries
50 within conflict zones are observed in just under half of children (45%), its prevalence
51 increasing in blast injuries (69%)(49), with a retrospective study finding 100% of traumatic
52 amputations and 96% of bone injuries to hand and foot were secondary to blast injuries(39).
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56 Studies describe extreme variation in the prevalence of upper limb injuries following blasts,
57 ranging from 6-74% (13,25,40,41,47,48,58,67,69,29,32,33,35-39), with the greatest upper
58 limb injury reported following UXO and cluster munition strike(41,44). Compared to adult and
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3 particularly following ERW blast, children were more likely to sustain upper limb injuries
4 (62,67,70–73) with a corresponding increase of 150-300% requiring operative amputation,
5 typically at the level of the finger (37,66,71,72). Traumatic amputation of the upper limb was
6 common and limited to the hands in 44-94% of children sustaining upper limb injuries(38,41),
7 while trans-radial and trans-humeral amputation was less frequent (14-34%)(25,48) but were
8 more likely to be bilateral(79). Arm fractures necessitating surgical fixation were observed in
9 45%(29), while upper limb vasculature was commonly disrupted(17,32,48).

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11 Similarly, prevalence of lower limb injuries shows variation between studies on blast affecting
12 25-86% of children(13,25,48,67,29,35–38,40,41,47), with landmine strikes particularly
13 associated with lower limb injury(35,37,41); 20-29% required operative amputations, normally
14 at the trans-tibial plane(37,38,79). Lower limb injuries were less common in children compared
15 to adults(62,70,72–74), with incidence lowest in 0-3 year olds(22), while increasing in
16 adolescents to mirror adults(62). Traumatic amputations were less frequent compared to the
17 upper limb, occurring in 14-35% of lower limb injuries(25,41,48).

18
19 Landmines drive debris, footwear and clothing upward between planes of the soft tissues and
20 bone, leading to degloving injuries of the leg, perineum and lower abdominal viscera, as well
21 creating serious potential for soft tissue and bone infection in the remaining limb(84,90). While
22 large bony defects of the lower limb are problematic in children(93), reconstruction with limited
23 shortening (<2 cm) has been associated with good outcomes, with the capability for highly
24 active growth plates to remodel and compensate for this (39,94). However, 75% of new growth
25 occurs in the distal femur and tibia growth plates, with the distal limb most prone to explosive
26 disruption(84).

27
28 The long term physical, psychosocial and financial repercussions of amputation must not be
29 underestimated. Physical complications are greatest following TA and below knee
30 amputations, and include anterior and varus bowing, heterotopic ossification and osseous
31 overgrowth requiring operative or prosthetic revision(95). Overgrowth is particularly
32 problematic in younger patients (under 12 years), with 15% of patients sustaining amputations
33 requiring re-vision of their stump. Protracted phantom limb sensation (PLS) and phantom limb
34 pain (PLP) is reported in over 50% of children following blast related amputation, similar to
35 that seen in adult literature following blasts(96), yet over five times higher than in children
36 requiring amputation following non-traumatic indications such as malignancy. Increased PLS
37 has been reported in lower limb amputations, while PLP was increased in upper limb
38 amputations (22,100). Social acceptance of the child amputee is culturally specific, with
39 stigmatisation in certain cultures negatively impacting the child's psychological, social and
40 educational status(97). While there is a paucity of outcome and long term costing studies in
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LMICs, the financial burden of prolonged rehabilitation and repeated revision of prosthesis on the children and host country's health system is likely to be considerable(97).

Like adults involved in blast trauma, older and adolescents children are prone to extremity injury, particularly of the upper limb, while infants and toddlers experience less extremity injuries. Limb injury causes diverse complications in the growing child with increased requirement for re-revision compared to adults.

Burn injuries

Multiple retrospective studies have noted that the majority of burns in children result from civilian mechanisms such as scalding, open fires and flash burns from household cooking fuels (15,16,46,98,99), while approximately 9-12% is the result of high-order explosives observed in combat blast modalities(46,99), less than observed in adult combat populations (52%)(100). Unlike civilian mechanisms however, blast-induced burns rarely occur in isolation, with multidimensional injuries playing a significant role in the child's prognosis(33,50,99). While post-mortem findings following the Syrian Civil War attributed only 0.5% of deaths being secondary to burns(63), conflict-related burn victims had higher mortality compared to non-conflict related burn victims (47% vs 3%)(98), and significantly greater than blast related burns in adult military populations (5%)(100). Severe burns following blasts were sustained in 30% of children, and fatal in 36-40%(18,40).

Creamer(38) noted the median age of burn victims as 6 years old. At this young age, the anatomical disproportionality of the child increases the total body surface area (TBSA), resulting in significant burn surface area (BuSA). Thus, approximately half of paediatric burns in conflict zones result in BuSA >15% (32,127), while 13% of children have BuSA exceeding 40%(127). A high BuSA exceeding 40% has been linked to myocardial damage and hypotension, making hemodynamic management challenging, while complications including nosocomial infection of the burn eschar and pneumonia are not uncommon(98). Within LMICs, protein loss and weight based fluid resuscitation is complicated by malnourishment, while cold fluids may accentuate hypothermia(46).

In conflict related burns, the head and neck are most frequently affected, potentially leading to thermal inhalation injuries(50,99). Thermal inhalation injuries in paediatric victims are difficult to assess, and clues to inhalational injuries such as increased respiratory rate may be incorrectly interpreted in the context of physiological age discrepancies. In addition the paediatric subglottis represents the narrowest section of the upper airway, and deteriorates rapidly from burn-induced laryngeal oedema, especially in the context of failed intubation

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3 attempts(101) leading to rapid oxygen desaturation. Between 21-33% of children were
4 identified as having inhalational injuries requiring pre-emptive or immediate intubation to
5 protect the airways(50,53), similar to that seen in adult combat casualties (26%)(100). Of this
6 paediatric cohort with inhalational injuries, 39% died(50), significantly greater than in adult
7 populations (4%)(100).
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12 Prognosticating factors noted for burns include increased time to presentation, prolonged
13 hospital length of stay and requirement for critical care input(98). This relates to the resource-
14 intensive management of the paediatric burns patient. Like adults, hospital length of stay for
15 burns patients are 2-3 times that of the general paediatric population(36,99), while ICU
16 requirements are increased, particularly in burns secondary to blast injuries(98,99). Operative
17 demands of paediatric burn victims are significant. Children aged 6 months to 3 years were
18 between 4-14 times more likely than adults to require surgical input , reflecting the significant
19 burden of burns (39% of this cohort compared to 2-6% in adults(102)). While other conditions
20 may be treated by a single operation, burns often require serial procedures(102), with an
21 average 2 operations per patient. This creates a disproportionate operative volume in both
22 adults and paediatric patients compared to other surgical emergencies(102). Burns induced by
23 blast injuries require more escharotomies (27% vs 4% $P<0.001$) and fasciotomies (67% vs
24 30% $P=0.002$) when compared to civilian burn mechanisms(98).
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34 Additionally, the requirement for post-operative support and rehabilitation add to the resource
35 requirements. Children are rarely left without functional sequelae, with limited joint mobility
36 and impaired tactile sensation presenting significant future challenges for rehabilitation(103),
37 while high rates of psychological morbidity including suicidal ideation have been reported in
38 adolescents(104). Under-resourcing psychological and functional rehabilitation will likely lead
39 to high rates of morbidity and mortality(102). The degree to which these services are available
40 within conflict zones and LMICs is uncertain. Ethical questions naturally arise when performing
41 interventions where health systems are unlikely to address a child's long term needs.
42 Examination of existing paediatric burn services within zones of interest and longer term follow
43 up of paediatric blast burn patients are required to determine the problems and needs for this
44 cohort.
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52 **Service provision**

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55 Relative to total admissions, paediatric victims affected by blasts constitute a
56 disproportionately large resource burden on operative workload, as well as intensive care and
57 hospital beds. Approximately 47-82% of paediatric blast victims require
58 surgery(22,33,36,58,61), particularly adolescents(22). The requirement for multiple operative
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3 procedures were common in the paediatric cohort, especially in burn and orthopaedic surgery
4 due to the requirement for surgical revision (34-80% of children required ≥ 2
5 procedures(16,18,36,38–40,42,54); 25% required ≥ 4 procedures)(16). Operative requirement
6 was greatest in 9-14 year olds, requiring on average 5 procedures per patient, prolonged ICU
7 and hospital stay, while 0-3 year olds required the least operative management(20). This study
8 suggested the reduced requirement for operative input in 0-3 year olds may be due not only
9 to the reduced burden of extremity injuries requiring repeated debridement, but potentially
10 because the equipment was inappropriate for this young cohort. This is supported by
11 observations that infants and young children aged 0-10 years old with an Injury Severity Score
12 ≥ 15 were 4x less likely to go to surgery compared to adults, while adolescents (11-15 years)
13 were 2x more likely to receive operative input(22).

21 Multidisciplinary surgical services were required in 80% of patients, with orthopaedic, plastic,
22 general neurosurgical, ophthalmic and vascular surgeons often working in partnership(48).
23 Debridement and primary skin closure represented the most common procedure, in 35-100%
24 of studies(25,29,36–38,47,58,68), in keeping with shrapnel injuries leading to multiple and
25 frequently contaminated superficial injuries(29,47). Children are likely to do well with thorough
26 debridement, with well perfused tissues allowing optimal healing and scar formation(39,94).

31 Retrospective studies of US military medical treatment facilities (MTF) in Afghanistan have
32 found that while children comprised only 3-6% of their total admissions, this demographic
33 required approximately double the total bed spaces (7-11%)(14,19,53), and on average 3x the
34 length of stay (LOS) of coalition troops admitted over the same time period(14,68).
35 Approximately 40% of paediatric admissions required a LOS exceeding 7 days, while, in half
36 , the LOS exceeded 14 days(10,33). Spinella et al noted that while children aged 11-17 were
37 the greatest proportion of children occupying beds, <1 year old cohort had the longest
38 stay(68). This contrasts with other studies finding young children <8 years old had the shortest
39 LOS, while children(8-14 years old) had the longest(14,18).

46 A similar burden is observed in the intensive care unit (ICU), with between 20-45% children
47 requiring ICU admission(5,30,33,36,43,50,53,54,61), the majority following explosive or
48 ballistic trauma. Children were often younger (0-10 years old)(22), with one recent study noting
49 children aged <1 year and 1-4 years most often requiring admission (53 & 66%
50 respectively)(30). Children under 8 required a ICU LOS over twice that of children aged >8
51 years (52). Harris et al(5) noted that despite representing only 12% of admissions, children
52 occupied on average 35% of ICU beds, with a brief surge in numbers resulting in 100%
53 occupancy from children, the majority requiring ventilatory and ionotropic support. This
54 specialised service was often provided by non-paediatric experts, which could result in 2
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3 healthcare providers per paediatric patient(5). Ventilatory equipment is often age specific, and
4 although multiple examples of ingenuity and adaptation of adult equipment exist(5,54),
5 children may overwhelm the unprepared MTF.
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9 One of the key challenges is providing sustainable health services in the host country. MTFs
10 may be capable of delivering exceptional paediatric care in the acute phase following blasts,
11 but recovery from morbidity is dependent on long term rehabilitation(94) normally provided by
12 the host country. Not only can this place exceptional strain on local health authorities, but if
13 provisions are not available, the child is likely to undergo a protracted decline(5,94).
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18 Reasons for the high rate of admission and prolonged stay may be multifactorial. Admission
19 criteria for host nationals to a coalition MTF typically require threat to life, limb, or eyesight,
20 with resulting prolonged stay. Interestingly however, children with mild to moderate traumata
21 are three times more likely than adults to be admitted (22). This may reflect a lack of certainty
22 in initial assessment of injury severity from health practitioners unaccustomed to dealing with
23 children. Within conflict zones, rearwards evacuation of civilians is not always possible, and
24 health interventions such as ventilatory support may not be sustainable by host countries
25 without deterioration in service standards, leading to prolonged admission until the child can
26 be safely moved(5).
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33 Following up recovery is a recurring theme when exploring long term challenges of blast
34 injuries in children(6). Children are a complex cohort to monitor. Geographical displacement,
35 particularly in the context of a conflict, increases the likelihood of this vulnerable cohort being
36 lost to follow-up. This can impact not only the child's rehabilitation and coordination with local
37 health authorities, but also cause difficulty in assessing long-term functional outcomes which
38 are needed to detect future health needs. Increasingly there is recognition of the need for
39 formalised trauma registries accessible in the host country, assisting the follow-up of this
40 vulnerable demographic(6,18,19,53).
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47 **Conclusion**

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50 Apart from their focus on paediatric blast, all the papers in this review have one thing in
51 common. Their research is based on those child patients injured by blast in conflict zones,
52 post-conflict zones and low resource environments. Most paediatric blast injury is inflicted in
53 these settings but is not exclusive to them. In Britain in May 2017, a bomb detonated at the
54 Manchester Arena killing 23 people and injuring 139, most of whom were children. The attack
55 placed a sudden and significant burden on medical services in the city, which had no
56 experience of paediatric blast injury in the 21st century, let alone on this kind of scale.
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3 Wherever in the world they live, and whatever the circumstances of the explosion, the social
4 and anatomical profile of children makes them uniquely vulnerable to one of the most complex
5 and demanding trauma conditions that any medical professional or system can treat. This
6 paper has characterised paediatric blast as a diverse injury pattern, which must be seen as
7 distinct from its adult equivalent. This pattern should be fully understood from point of
8 wounding through the post-operative and rehabilitation phases of treatment. This continuum
9 approach would enable both better long-term care of the patient, and improved support of
10 medical systems bearing the intense burden of that care.
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16 It remains to be seen whether the monitoring of the long term effects of paediatric blast injury
17 in well-resourced environments is any better than that in areas of instability. Monitoring of
18 patient outcomes should be integrated with the monitoring of treatment so that relevant
19 practice and skills can be continually assessed. It is urgent that the understanding of
20 paediatric blast injury is given focus and structure, not just for the likely significant patient
21 cohort of the future but for those suffering today as blast injured children surviving into blast-
22 blighted adulthood, wherever they live in the world.
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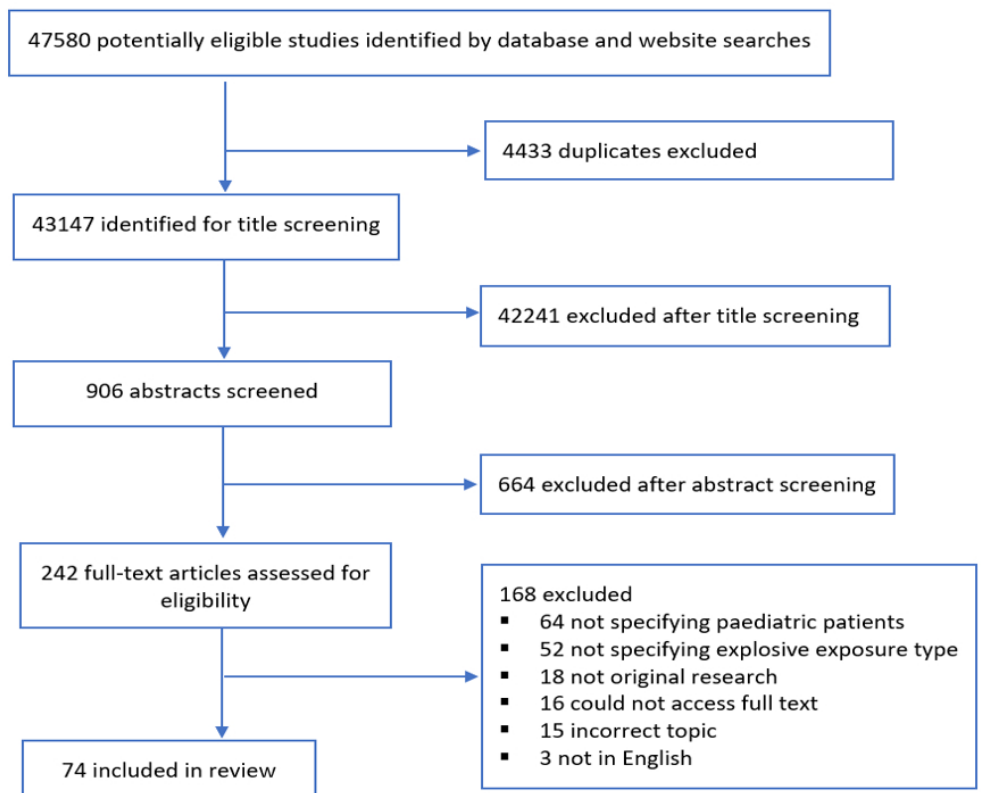
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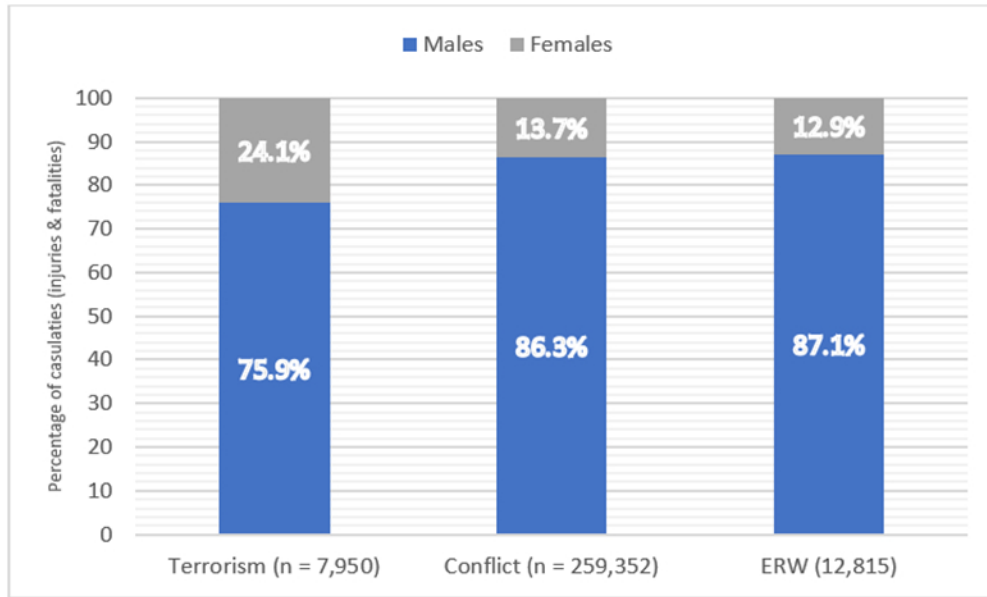
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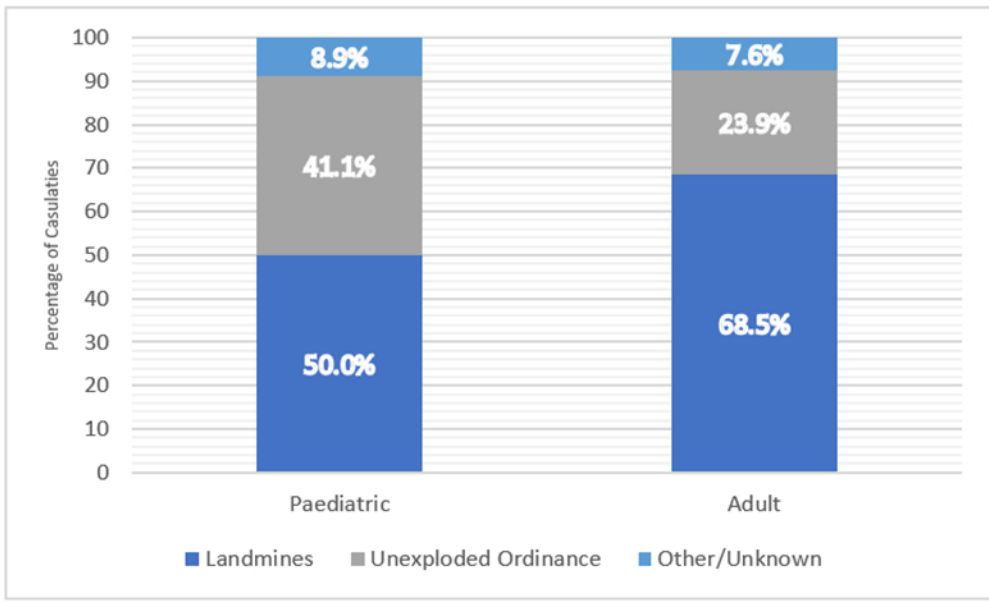
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Blast Injuries in Children: a mixed-methods narrative review.

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39 **Patient and public involvement statement:**

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42 **No patients or members of the public were involved in this review.**
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Key questions

What is already known on this topic?

- Approximately one in six children live in conflict zones, where exposure to blast injuries is not uncommon. Blast injuries have the potential to inflict significant mortality and morbidity upon the global paediatric population living in conflict zones.
- Describing the characteristics of injuries sustained by the paediatric population is essential in advancing local and global health policies. Despite this, common themes related to paediatric injury following to blasts are poorly described.

What this study adds?

- Paediatric victims are most likely to be male, with victims following conflict and explosive remnants of war (ERW) typically 4-10 years old. Of these victims, agricultural occupation and poor educational status is related to level of exposure.
- Head injuries are the leading cause of death in 46-71% of paediatric victims, and strongly associated with facial and ocular injuries conferring significant social and economic implications to the victims.
- Injuries to the extremities are seen in approximately half of children exposed to blast trauma, with upper limb injuries requiring between 1.5 to 3 times more operative intervention compared to adults. Functional repercussions of these injuries are significant, with 15% of traumatic amputations in the lower limb frequently requiring operative and prosthetic re-revision.
- An influx of paediatric patients can rapidly overwhelm health facilities, with between 47-82% of children requiring surgical intervention, of which 25% required over 4 procedures. Greater requirement for intensive care support in addition to prolonged inpatient and rehabilitative stays contributes to considerable service strain.

Abstract

Background and significance. Blast injuries arising from high explosive weaponry is common in conflict areas. While blast injury characteristics are well recognised in the adults, there is a lack of consensus as to whether these characteristics translate to the paediatric population. Understanding blast injury patterns in this cohort is essential for providing appropriate provision of services and care for this vulnerable cohort.

Methods. In this mixed-method review, original papers were screened for data pertaining to paediatric injuries following blasts. Information on demographics, morbidity and mortality and service requirements were evaluated. The papers were written and published in English

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3 from a range of international specialists in the field. Patient and public involvement
4 statement: No patients or members of the public were involved in this review.
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7 **Results.** Children affected by blast injuries are predominantly male and their injuries arise
8 from explosive remnants of war, particularly unexploded ordnance. Blasts show increased
9 morbidity and mortality in younger children, while older children have injury patterns similar
10 to adults. Head and burn injuries represent a significant cause of mortality in young children,
11 while lower limb morbidity is reduced compared to adults. Children have a disproportionate
12 requirement for both operative and non-operative service resources, and provisions for this
13 burden are essential.
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19 **Conclusions.** Certain characteristics of paediatric injuries arising from blasts are distinct
20 from that of the adult cohort, while the intensive demands on services highlights the
21 importance of understanding the diverse injury patterns in order to optimise future service
22 provisions in caring for this the child blast survivor..
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Introduction

Approximately one in six children live in conflict zones, with the main global burden borne by citizens of low and middle income countries (LMICs)(1). Children enmeshed in conflict and post-conflict zones are frequently exposed to high-order explosives (HE), either through explosive remnants of war (ERW) such as landmines and unexploded ordinance (UXOs), military ordinance such as shelling and aerial bombardments or acts perpetrated by non-state actors such as improvised explosive devices (IEDs) and suicide bombing(2). HE can inflict unique and unusual injuries upon the child through the blast over-pressure wave (primary blast injury), energisation of materials causing fragmentation (secondary blast injury), bodily displacement or crush injuries (tertiary blast injuries) and through burns, inhalation, toxic or psychological trauma (quaternary blast injuries)(3).

The UN Convention on the Rights of the Child (UNCRC) seeks to secure both the safety and well-being of all the world's children. The long-term consequences of conflict injury constitutes grave violations of numerous articles, including Article 3 which calls for signatories to recognise the best interest of the child "in all decisions and actions that affect children." Similarly, Article 6 recognises every child's right to life and development, and Article 28 seeks to ensure their right to education. Article 23 specifies that children with a disability "have the right to live full and decent lives," and Article 39 states that children...who are victims of war must receive special support to help them recover...". Blast injury and its immediate effects are covered by Article 3.3 which states that medical care of the child be delivered and supervised by providers competent in that field(4). However, paediatric care in conflict zones is often delivered by personnel for whom experience of dealing with paediatric blast injuries is unusual(5). Primary studies increasingly recognise the complex patterns of injury sustained in the adult population following blast exposure(3), however there is a lack of consensus as to whether applying lessons learnt from the adult population translates appropriately into paediatric cohorts(6). Bree et al(7) argue that principles for life-saving interventions, such as prioritising catastrophic haemorrhage, airway, breathing and circulation are just as applicable in children as adults. Conversely Fendya et al(8) contend that directly applying adult trauma principles to the paediatric population neglects the social, anatomical, physiological and psychological differences between adults and children, affecting the validity of these inferences.

While primary studies have described injuries sustained by the blast injured child, no study has attempted to synthesise the data to identify recurrent characterises in this vulnerable cohort. Understanding the characteristics of such injuries to the paediatric population will advance efforts to prevent, mitigate, and treat these injuries in domestic and deployed health

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3 systems(3). The aim of this review is to provide an overview of injury patterns and
4 challenges in caring for the blast-injured child, in order to define future research needs for
5 protection, mitigation, immediate medical treatment, and rehabilitation.
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8 9 **Methods**

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12 In this mixed-methods review, original peer-reviewed quantitative, qualitative and mixed-
13 method observational studies, in addition to grey literature, were screened for data on
14 explosive injuries in paediatric cohorts. By utilising all study designs, greater capture of
15 relevant literature was achieved, although this meant the data was unsuitable for a formal
16 systematic review. PubMed and Scopus (including Embase) were searched. Search terms
17 including “Paediatric” OR “Pediatric” OR “Child*” OR “Children” AND “Blast” OR “Explosi*”
18 OR “Explosion” were used to capture potential studies. Articles had to be written in English
19 and published before December 16, 2018. Studies involving adult as well as children were
20 included, in addition to articles where the mechanism of injury was mixed. This decision was
21 taken in order to accurately reflect the settings the studies represent, where victims in
22 conflict zones are heterogenous and subject to a variety of combat related mechanisms.
23 Studies were omitted if they did not specify explosive mechanisms or include children.
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28 Children are defined as all humans under the age of eighteen years (as specified by the
29 United Nations Convention on the Rights of the Child)(4). The heterogeneity and arbitrary
30 nature of what defines a child is acknowledged, and studies often utilise individual
31 definitions. Within this review ages are defined thus: <1 year are infants, 1-8 are young
32 children; 9-13 are older children and 14-18 are adolescents.
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35 36 **Patient and public involvement statement:**

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39 No patients or members of the public were involved in this review.
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Results

Figure 1: Study selection

Study selection of the 74 studies included in this review are shown in figure 1. Of these, 26 utilise trauma registries (table 1), 26 single centre hospital based case series (table 2), 8 use multi-centre hospital based case series (table 3), 13 use community surveillance (table 4) while 1 uses grey literature (table 5).

Table 1. The 26 studies utilising trauma registries

	Monitoring period	Location	Setting	Sample Size	Population	Exposure	Study	Effect investigated
Aharonson-Daniel et al (2003)(9)	2000-2001	Israel	Civilian	138	Paediatric (100%)	IEDs/Suicide IEDs (67%) GSW (25%) Other (8%)	Retrospective. National Trauma Registry	Injuries and mortality
Aharonson-Daniel et al (2006)(10)	2000-2004	Israel	Civilian	115	Paediatric (8%) Adult (92%)	Suicide IEDs (100%)	Retrospective. National Trauma Registry	Injuries and mortality
Amir et al (2005)(11)	2000-2002	Israel	Civilian	148	Paediatric (100%)	IEDs/Shelling (66%) GSW (34%)	Retrospective. National Trauma Registry	Injuries and mortality
Bilukha et al (2015)(12)	2010-2013	Iraq	Civilian	2803	Paediatric (13%) Adult (87%)	IEDs (49%) Other/Unknown (51%)	Retrospective. Military Trauma Registry	Injuries and mortality
Bitterman et al (2016)(13)	2013	Israel	Military	84	Paediatric (100%)	IEDs/Shelling (67%) GSW (23%) Non-Combat (10%)	Retrospective. Military Trauma Registry	Injuries and mortality
Borgman et al (2012)(14)	2001-2011	Afghanistan Iraq	Military	128582	Paediatric (6%) Adult (94%)	Non-Combat (40%) IEDs/Shelling (38%) GSW (22%)	Retrospective. Military Trauma Registry	Injuries and mortality
Borgman et al (2015)(15)	2003-2011	Afghanistan Iraq	Military	549	Paediatric (100%)	Non-Combat (84%) IEDs/Shelling (11%) Other/Unknown (5%)	Retrospective. Military Trauma Registry	Injuries and mortality
Creamer et al (2009)(16)	2004-2007	Afghanistan Iraq	Military	2090	Paediatric (100%)	GSW (29%) IEDs/Shelling (24%) Other/Unknown (22%) Non-combat (25%)	Retrospective. Military Trauma Registry	Injuries and mortality
Dua et al (2013)(17)	2006-2008	Iraq	Military	25	Paediatric (100%)	IEDs/Shelling (72%) GSW (28%)	Retrospective. Military Trauma Registry	Injuries and mortality
Edwards et al (2012)(18)	2002-2012	Afghanistan Iraq	Military	4913	Paediatric (100%)	IEDs/Shelling (100%)	Retrospective. Military Trauma Registry	Injuries and mortality
Edwards et al (2014)(19)	2002-2012	Afghanistan Iraq	Military	6273	Paediatric (100%)	IEDs/Shelling (23%) GSW (16%) Other/Unknown (4%) Non-Combat (57%)	Retrospective. Military Trauma Registry	Injuries and mortality
Edwards et al	2002-2010	Afghanistan	Military	4928	Paediatric (100%)	IEDs/Shelling (100%)	Retrospective.	Injuries and

(2014)(20)		Iraq					Military Trauma Registry	mortality
Hillman et al (2016)(21)	2003-2014	Afghanistan Iraq	Military	27	Paediatric (100%)	IEDs /Shelling (59%) GSW (26%) Non-combat (15%)	Retrospective. Military Trauma Registry	Injuries and mortality
Jaffe et al (2010)(22)	2000-2005	Israel	Civilian	837	Paediatric (14%) Adult (86%)	IEDs (100%)	Retrospective. National Trauma Registry	Injuries and mortality
Khan et al (2015)(23)	2010-2011	Pakistan	Civilian	103	Paediatric (16%) Adult (84%)	IEDs (100%)	Retrospective National Trauma Registry	Injuries and mortality
Kluger et al (2004)(24)	2000-2003	Israel	Civilian	906	Paediatric (7%) Adult (93%)	IEDs (100%)	Retrospective. National Trauma Registry	Injuries and mortality
McKechnie et al (2014)(25)	2008-2012	Afghanistan	Military	766	Paediatric (100%)	IEDs/Shelling (51%) GSW (28%) Non-combat (21%)	Retrospective. Military Trauma Registry	Injuries and mortality
Naylor et al (2018)(26)	2007-2016	Afghanistan Iraq	Military	3439	Paediatric (100%)	IEDs/Shelling (38%) GSW (20%) Non-combat (11%) Other/Not specified (31%)	Retrospective. Military Trauma Registry	Injuries and mortality
Neff et al (2014)(27)	2001-2013	Afghanistan Iraq	Military	1113	Paediatric (100%)	IEDs/Shelling (56%) GSW (32%) Non-combat (12%)	Retrospective. Military Trauma Registry	Injuries and mortality
Patregnani et al (2012)(28)	2002-2009	Afghanistan Iraq	Military	744	Paediatric (100%)	IEDs/Shelling (43%) GSW (26%) Non-combat (31%)	Retrospective. Military Trauma Registry	Injuries and mortality
Quintana et al (1997)(29)	1996	USA	Civilian	66	Paediatric (100%)	IED (100%)	Retrospective. National Trauma Registry	Injuries and mortality
Schauer et al (2018)(30)	2007-2016	Afghanistan Iraq	Military	3388	Paediatric (100%)	IEDs/Shelling (43%) GSW (22%) Non-combat (35%)	Retrospective. Military Trauma Registry	Injuries and mortality
Smith et al (2014)(31)	2003-2011	Afghanistan Iraq	Military	813	Paediatric (6%) Adult (94%)	IEDs/Shelling (77%) GSW (23%)	Retrospective. Military Trauma Registry	Injuries and mortality
Villamaria et al (2014)(32)	2002-2011	Afghanistan Iraq	Military	155	Paediatric (100%)	IEDs/Shelling (58%) GSW (37%) Other/Not specified (5%)	Retrospective. Military Trauma Registry	Injuries and mortality
Waisman et al (2003)(33)	2000-2002	Israel	Civilian	160	Paediatric (100%)	IEDs (67%) GSW (25%) Other/Not specified (11%)	Retrospective. National Trauma Registry	Injuries and mortality
Woods et al (2012)(34)	2003-2009	Afghanistan Iraq	Military	176	Paediatric (100%)	IEDs/Shelling (59%) GSW (21%) Non-combat (20%)	Retrospective. Military Trauma Registry	Injuries and mortality

Table 2. The 26 studies utilising single centre hospital based case series

	Monitoring period	Location	Setting	Sample Size	Population	Exposure	Study	Effect investigated
Al-Worikat et al (2001)(35)	1988-2000	Jordan	Civilian	226	Paediatric (10%) Adult (90%)	Landmines (100%)	Retrospective. Single centre Hospital based case series	Long term sequelae

Arul et al (2012)(36)	2011	Afghanistan	Military	82	Paediatric (100%)	IEDs/Shelling (52%) GSW (11%) Non-combat (37%)	Retrospective. Single centre Hospital based case series	Injuries and mortality
Bajec et al (1993)(37)	1991	Kuwait	Civilian	152	Paediatric (12%) Adult (88%)	Landmines (100%)	Retrospective. Single centre Hospital based case series	Injuries and mortality
Beitler et al (2006)(38)	2002	Afghanistan	Military	204	Paediatric (28%) Adult (72%)	Non-combat (44%) IEDs/Shelling (36%) GSW (20%)	Retrospective. Single centre Hospital based case series	Injuries and mortality
Bertani et al (2015)(39)	2009-2013	Afghanistan	Military	89	Paediatric (100%)	IEDs/Shelling (79%) GSW (21%)	Retrospective. Single centre Hospital based case series	Injuries and mortality
Coppola et al (2006)(40)	2004-2005	Iraq	Military	85	Paediatric (100%)	IEDs/Shelling (29%) Non-combat (44%) Other/Unknown (27%)	Retrospective. Single centre Hospital based case series	Injuries and Mortality
Can et al (2009)(41)	2001-2008	Turkey	Civilian	23	Paediatric (100%)	Landmines (87%) UXO (13%)	Retrospective. Single centre Hospital based case series	Injuries and mortality
Chehab et al (2018)(42)	2009-2012	Afghanistan	Military	81	Paediatric (100%)	IEDs/Shelling (67%) GSW (21%) Stabbing (12%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Er et al (2017)(43)	2013-2014	Syria	Civilian	1591	Paediatric (18%) Adult (82%)	IEDs/Shelling (77%) GSW (7%) Other/Unknown (16%)	Retrospective. Single-centre Hospital based case series	Injuries and Mortality
Fares et al (2013)(44)	2006-2011	Lebanon	Civilian	122	Paediatric (100%)	UXO (100%)	Retrospective. Single centre Hospital based case series	Long term sequelae
Fares et al (2014)(45)	2006-2013	Lebanon	Civilian	29	Paediatric (28%) Adult (72%)	UXO (100%)	Retrospective. Single centre Hospital based case series	Injuries and mortality
Gurney et al (2004)(46)	2003	Iraq	Military	78	Paediatric (100%)	IEDs/Shelling (7%) GSW (1%) Other/Not specified (9%) Non-Conflict (83%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Harris et al (2009)(5)	2008	Afghanistan	Military	15	Paediatric (100%)	IEDs/Shelling (87%) Other/Not specified (6%) Non-conflict (7%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Hinsley et al (2005)(47)	2003	Iraq	Military	79	Paediatric (10%) Adult (90%)	IEDs/Shelling (63%) GSW (37%)	Retrospective Single-centre Hospital based case series	Injuries and mortality
Hodalic et al (1999)(48)	1991-1992	Croatia	Military	1211	Paediatric (13%) Adult (87%)	IEDs/Shelling (95%) GSW (3%) Other/Not specified (2%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Inwald et al (2014)(49)	2011-2012	Afghanistan	Military	112	Paediatric (100%)	IEDs/Shelling (54%) GSW (29%) Non-conflict (17%)	Retrospective Single-centre Hospital based case series	Injuries and mortality
Jeevaratnam et al (2013)(50)	2010	Afghanistan	Military	88	Paediatric (35%) Adult (65%)	IEDs/Shelling (33%) Non-conflict (67%)	Retrospective Single-centre Hospital based case series	Injuries and mortality
Klumo et al (2010)(51)	2007-2009	Afghanistan	Military	43	Paediatric (100%)	IEDs/Shelling (67%) GSW (5%) Non-combat (28%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality

Matos et al (2008)(52)	2003-2004	Iraq	Military	1132	Paediatric (3%) Adult (97%)	IEDs/Shelling (64%) Non-combat (36%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
McGuigan et al (2007)(53)	2004	Iraq	Military	99	Paediatric (100%)	GSW (42%) IEDs/Shelling (35%) Other/Not specified (23%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Nordmann et al (2010)(54)	2008-2009	Afghanistan	Military	31	Paediatric (100%)	IEDs/Shelling (45%) GSW (32%) Non-combat (23%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Pannell et al (2015)(55)	2010-2011	Afghanistan	Military	263	Paediatric (100%)	IEDs/Shelling (42%) GSW (17%) Non-combat (41%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Pearce et al (2015)(56)	2011-2012	Afghanistan	Military	281	Paediatric (100%)	IEDs/Shelling (47%) GSW (13%) Non-combat (35%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Terzic et al (2001)(57)	1991-1995	Bosnia Croatia	Civilian	92	Paediatric (100%)	IEDs/Shelling/UXO (100%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Thompson et al (2017)(58)	2006-2013	Afghanistan	Military	295	Paediatric (100%)	IED (68%) UXO (4%) Other/Not specified (28%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Walker et al (2010)(59)	2006-2007	Afghanistan	Military	78	Paediatric (100%)	IEDs/Shelling (64%) GSW (37%) Other/Not specified (5%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality
Wilson et al (2013)(60)	2010-2011	Afghanistan	Military	41	Paediatric (100%)	IEDs/Shelling (47%) GSW (12%) Non-combat (42%)	Retrospective. Single-centre Hospital based case series	Injuries and mortality

Table 3. The 8 studies utilising multi-centre hospital based case series

	Monitoring period	Location	Setting	Sample Size	Population	Exposure	Study	Effect investigated
Arafat et al (2017)(61)	2012-2013	Syria	Civilian	324	Paediatric (18%) Adult (82%)	IEDs/Shelling (57%) GSW (43%)	Retrospective. Multi-centre Hospital based case series	Injuries and mortality
Bendinelli et al (2009)(62)	2003-2006	Cambodia	Civilian	356	Paediatric (26%) Adult (74%)	Landmines (67%) UXO (33%)	Retrospective. Multi-centre Hospital based case series	Injuries and mortality
Celikel et al (2014)(63)	2012	Syria	Civilian	186	Paediatric (22%) Adult (78%)	IEDs/Shelling (67%) GSW (26%) Other/Unknown (7%)	Retrospective. Multi-centre Hospital based mortuary case series	Mortality
Celikel et al (2015)(64)	2012-2014	Syria	Civilian	140	Paediatric (100%)	IEDs/Shelling (70%) GSW (14%) Other/Unknown (16%)	Retrospective. Multi-centre Hospital based mortuary case series	Mortality
Gataa et al (2011)(65)	2005-2006	Iraq	Civilian	551	Paediatric (20%) Adult (80%)	IEDs (82%) GSW (18%)	Retrospective. Multi-centre Hospital based case series	Injuries and mortality
Hanevik et al (2000)(66)	1991-1995	Eritrea	Civilian	248	Paediatric (63%) Adult (37%)	Landmines (100%)	Retrospective. Multi-centre Hospital based case series	Injuries and mortality

Mirza et al (2013)(67)	2007-2011	Pakistan	Civilian	1142	Paediatric (6%) Adult (94%)	IEDs (100%)	Retrospective Multi-centre Hospital based mortuary case series	Injuries and mortality
Spinella et al 2008(68)	2001-2007	Afghanistan Iraq	Military	1305	Paediatric (100%)	Trauma (Unspecified) (100%)	Retrospective. Multi-centre Hospital based case series	Injuries and mortality

Table 4. The 13 studies utilising community surveillance

	Monitoring period	Location	Setting	Sample Size	Population	Exposure	Study	Effect investigated
Andersson et al (1995)(69)	1994-1995	Afghanistan Bosnia Cambodia Mozambique	Civilian	2100	Paediatric (100%)	Landmines (100%)	Retrospective. community surveillance	Socio-economic
Bilukha et al (2003)(70)	2001-2002	Afghanistan	Civilian	1636	Paediatric (46%) Adult (54%)	UXO (47%) Landmine (41%) Other/Unknown (12%)	Retrospective. Community Surveillance	Injuries and mortality
Bilukha et al (2007)(71)	1994-2005	Chechnya	Civilian	3021	Paediatric (30%) Adult (70%)	Landmines (41%) UXO (37%) Other/Unknown (22%)	Retrospective. Community Surveillance	Injuries and mortality
Bilukha et al (2008)(72)	2002-2006	Afghanistan	Civilian	5471	Paediatric (54%) Adult (46%)	UXO (50%) Landmines (42%) Other/Unknown (8%)	Retrospective. Community Surveillance	Injuries and mortality
Bilukha et al (2011)(73)	2006-2010	Nepal	Civilian	307	Paediatric (58%) Adult (42%)	IEDs (76%) Landmines (4%) Other/Unknown (20%)	Retrospective. Community Surveillance	Injuries and mortality
Bilukha et al (2013)(74)	2008-2011	Nepal	Civilian	437	Paediatric (14%) Adult (76%)	IEDs (69%) Other/Unknown (31%)	Retrospective. Community Surveillance	Injuries and mortality
Guerriero et al (2014)(75)	2013	USA	Civilian	11	Paediatric (100%)	IEDs (100%)	Prospective. Community Surveillance	Long term sequelae
Guha-Sapir et al (2018)(76)	2011-2016	Syria	Civilian	101453	Paediatric (17%) Adult (83%)	Shelling/Air bombardment (57%) Other/Not specified (43%)	Retrospective. Community Surveillance	Mortality
Hemmati et al (2015)(77)	1988-2013	Iran	Civilian	78	Paediatric (100%)	Landmines (100%)	Cross-section. Community surveillance	Long term sequelae
Kinra et al (2003)(78)	1991-2000	Bosnia and Herzegovina	Civilian	4064	Paediatric (14%) Adult (86%)	Landmines (100%)	Retrospective. Community Surveillance	Injuries and mortality
Mousavi et al (2015)(79)	2014	Iran	Civilian	78	Paediatric (100%)	Landmines (80%) UXO (20%)	Retrospective. Mixed-method community surveillance	Long-term sequelae/ Injuries and mortality
Pat-Horenczyk et al (2007)(80)	2006	Israel	Civilian	695	Paediatric (100%)	IEDs (100%)	Retrospective. Mixed-method community surveillance	Long term sequelae
Poor Zamany Nejat et al (2016)(81)	2015	Iran	Civilian	41	Paediatric (100%)	Landmines (100%)	Retrospective mixed-method community surveillance	Long term sequelae

Table 5. The 1 study utilising grey literature

	Monitoring period	Location	Setting	Sample Size	Population	Exposure	Study	Effect investigated
Guha-Sapir et al (2015)(82)	2011-2014	Syria	Civilian	78769	Paediatric (16%) Adult (84%)	IEDs/Shelling (75%) GSW (25%)	Grey-literature	Mortality

Demographics

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3 Following the use of explosive weaponry by non-state actors against civilians, the most
4 commonly injured paediatric cohort are males aged 10-18 years old(9,11,33), while children
5 involved in conflict and ERW blast injuries were generally aged between 4-10 years
6 old(18,59). Perpetrators target busy areas such as restaurants and nightclubs which older
7 children and adolescents might frequent (10,11,33), while cultural factors within LMICs in
8 these social areas result in a predominantly male cohort (9,10,12,22–24,33,67,75,80).
9 Similar gender finding are observed in children following conflict and ERW related injuries
10 where all studies showed male predominance in victims, with over 70% male in three
11 quarters of the studies (Figure 2).
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20 Figure 2. Gender differences in in casualties following blast
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22 ERW contribute considerable morbidity and mortality both during and following conflict. As
23 seen in figure 3, children were more likely to be injured by UXO compared with adults, while
24 landmines affected a predominately adult cohort (35,37,41,62,69,70,72,73,78). It should be
25 noted that statistics on pre-hospital mortality for children in conflict settings is generally an
26 underestimation due to the difficulties in reporting and monitoring. It should be noted overall
27 that there is limited statistical information available currently to researchers wherever they
28 work with blast injured children and that thus the percentages used in some of the papers
29 they considered were unable to be supported with the full range of statistical confirmation. It
30 is hoped that this review will provide focus for those organisations that seek to provide
31 statistics on child conflict injuries, for instance many explosive weapons observation groups
32 do not or who are unable to distinguish between adults and children in their reporting.
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43 Figure 3. Percentage of Casualties (injuries and fatalities) by specific modalities
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45 UXOs have been described as small, colourful and toy-like, promoting child interaction and
46 subsequent injury from handling, resulting in often fatal upper limb, head, neck or chest
47 injury(41,44,62,83,84). Due to the social nature of children, these interactions commonly
48 occur in groups, leading to multiple casualties in 45-63% of events involving children
49 compared to 30-40% in adults(70,78,79).
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54 Occupation and education play a role in ERW injuries. It is common for children in LMICs,
55 particularly males, to assist their family with herding and farming as opposed to attending
56 school. This may affect the likelihood to exposure to ERWs through increased freedom to
57 roam where such devices are present(25,42,64,72). A lack of formal education impacts the
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3 child's ability to read warning signs; only 6-22% of victims were aware ERWs were
4 present(27,80) and of these, only 0-11% had received ERW risk education(23,25,27,80).
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7 Children are particularly vulnerable to wide-area explosives such as aerial bombardment and
8 shelling, particularly in the primarily urbanised environments of modern conflicts. In the
9 Syrian Civil War, three quarters of wide-area explosives were used in civilian residential
10 areas that children frequent, with these mechanisms responsible for 82% of child
11 deaths(76,82).
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16 The following section reviews what is known of mortality in children before reviewing injury
17 types.
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20 21 **Mortality**

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23 Comparison of paediatric wartime mortality data is difficult as many studies do not
24 differentiate mechanism of injury. Edwards et al(85) study on 4,913 children between 2002-
25 2010 presenting with blast injuries remains the single largest data set. The reported mortality
26 rate of 8% matches well with the mortality rates of 6-9% quoted in paediatric trauma deaths
27 from Iraq and Afghanistan, although these studies displayed all trauma mechanisms as
28 opposed to specifying blast trauma(14,16,20,25,36,40). Between 2006-2013, Thompson et
29 al. (58) noted a mortality rate over double of that quoted by Edwards et al. following
30 paediatric blast injury in Afghanistan (18%). Operational tempo and the increasing use of
31 IEDs have been hypothesized to underlie these discrepancies in mortality(58).
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39 Age related variation in mortality has been described. Matos et al noted mortality was
40 highest at 24% in young children (5-8 year old)(52) while Schauer et al and Spinella et al
41 found greatest mortality in 0-4 years(30,68). Similarly, Borgman et al and Matos et al noted
42 that children <8 years old had increased trauma mortality compared to 8-16 year olds (10-
43 18% vs 4-7%)(15,52), while Spinella et al noted a similar increase in mortality in young
44 children (<6 year old) compared to 6-16 year olds (11% vs 4%)(68). Few studies directly
45 compare adult and paediatric mortality, and comparisons between studies are difficult due to
46 methodological differences. What is common is that mortality in children following combat
47 related trauma is considerably higher than that of paediatric non-combat trauma (2-3%)(86)
48 and adult military combat casualties (1-3%)(87,88).
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55 A wide range of paediatric mortality is reported following mine strikes, ranging from 4-
56 46%(41,44,62,69-74,83). Shuker et al(89) suggested that approximately half of paediatric
57 victims die within minutes of mine explosion, likely due to penetrating head injury, and
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3 catastrophic haemorrhage causing non-survivable injuries, in keeping with adult
4 literature(87,88). Time critical injuries following blasts may represent particular problems in
5 LMIC's, where pre-hospital evacuation chains may be protracted. Coupland(90) noted that in
6 1991, only 14% of paediatric and adult ERW victims were admitted in under six hours, while
7 the majority (58%) were admitted between 6-24 hours and 28% presented after 24 hours.
8 Even in recent conflicts, Bitterman et al(13) found <10% of children presented within 1 hour,
9 with over a third presenting after 6 hours. Protracted evacuation of paediatric victims add to
10 blast mortality, reinforced by studies observing a 85-91% mortality of children either at scene
11 or en-route to health facilities(73,89).

19 **Vascular injuries**

21 Penetrating injuries occur in 38-76% of blast-exposed children (9,10,14,16,33,36,37,55), with
22 incidence greater in older children aged 10-16 compared to 0-10 year olds (65-83% vs 47-
23 63%)(22,52). In keeping with penetrating injury patterns, vascular injury was observed in 3-
24 12% of children following blast trauma (9,32,33,37), considerably higher compared to non-
25 blast conflict trauma where vascular injury occurred in 0.6-1% of paediatric
26 victims(9,10,24,32,53).

32 Vascular damage and subsequent haemorrhage following explosions have been identified
33 as a significant cause of childhood fatalities, ranging from the primary cause of death in 21-
34 38% during the Syrian Civil War(63,64) to 63% following IED and suicide attacks in
35 Pakistan(67), while mortality rates following penetrating injuries in civilian settings are
36 considerably lower (5%)(32). Extremity trauma was most highly associated with vascular
37 injuries, with the majority of vascular injuries occurring in the lower limb (38-58%) followed
38 by the upper limbs (25-28%)(17,32). This is in keeping with adult data where 54% of injuries
39 were sustained to the extremities(87). Despite its high prevalence, extremity vascular
40 wounds confer reduced risk of death compared to vascular damage within the torso,
41 attributed as the primary cause of death in 71% of paediatric deaths and conferring a four-
42 fold increased risk of death compared to extremity vascular injuries(32).

50 Data on vascular damage is clear: older children and adolescents sustain similar rates of
51 vascular injury to adults, particularly to the extremities, while mortality following penetrating
52 trauma is primarily the result of injuries to the vasculature within the torso.

56 **Head injuries**

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3 The prevalence of head injuries following blasts are diverse, ranging from 6-54%
4 (10,11,40,42,43,47-49,53,13,16,18,32,33,36,38,39), while adult combat data ranges from
5 16-29%(87). This variation is due to the heterogenous definitions of head injury described in
6 these studies, with few studies differentiating between superficial scalp wounds, blunt
7 traumatic brain injury (TBI) or penetrating TBI. Where head injuries were documented, TBI
8 was recorded in 21-62% of paediatric victims, of which 38-39% were defined as
9 penetrating(33,45,48). Unsurprisingly, papers noted over double the incidence of paediatric
10 penetrating head injury in blast trauma compared to mainly blunt civilian trauma (13% vs
11 6%), while the reverse was true in closed head injuries, with half the incidence of closed
12 head injuries in blast injuries compared to civilian trauma (22% vs 44%)(9).

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20 Cerebral haemorrhage and direct cranial damage following blast have been attributed as a
21 leading cause of death in children, responsible for 46-71% of fatalities (36-38,43,101).
22 Creamer(38) noted penetrating wounds to the head accounted for 44% of child deaths in the
23 emergency department while open skull fractures with cerebral evisceration was
24 documented in 88% of paediatric fatalities following the 1995 Oklahoma City bombings(102).
25 While penetrating head injuries undoubtedly carry high mortality, Woods(34) noted that 8
26 children survived to hospital discharge despite penetrating head injuries deemed initially
27 unsurvivable, suggesting such are not unequivocally fatal.

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33 Er et al(43) noted that children were more likely to be injured in the head compared to adults
34 (54% vs 40%) following aerial and shelling during the Syrian Civil War, while young children
35 aged between 0-4 year old were more likely to undergo neurosurgical procedures compared
36 to other ages(20,51), 48% of which were craniectomies or craniotomies for penetrating brain
37 injury, mainly secondary to IED blasts(51). Suggested reasons for this increase may relate to
38 anatomical predispositions, particularly in infants, such as large head to body ratios in
39 addition to reduced skull rigidity(22) as well as the relatively shorter distance from the head
40 to ground-based ERW and IEDs compared to adults(18,22,62,84,89).

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47 There is a clear lack of studies investigating long term outcomes following blast- associated
48 head injuries. While significant cognitive, intellectual and functional sequelae arising from
49 non-blast TBI (nbTBI) have been described, controversy exists as to whether nbTBI is
50 analogous to blast-induced TBI(91), and the paucity of paediatric data means this
51 comparison is even more problematic.

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56 A unifying message is that head injuries are associated with high morbidity and mortality in
57 paediatric blast trauma, while the long term consequences remain largely unknown. Head
58 injuries are commonly penetrating compared to civilian practice, and increased operative
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3 demand in infants and toddlers for neurosurgical procedures may stretch medical service
4 expertise.
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6 7 **Facial and ocular injuries** 8

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10 Blasts result in injury to the face in between 27-48% of paediatric victims, compared to 12%
11 resulting from GSW(11,18,49) and 10% in adults(87). Relative to other blast related injuries,
12 facial injuries in isolation are associated with reduced mortality(18). However, Gataa (65)
13 noted that of the patients presenting with facial injuries, 29% had concomitant eye injury,
14 22% had TBI, while life-threatening facial bleeding occurred in 10% of patients. In addition to
15 physical sequelae, facial injuries are associated with functional and psychological disorders
16 stemming from stigmatisation of disfiguring injuries with implications for future social,
17 economic and marital prospects(65).
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20 Despite only comprising of 0.3% of the anterior body surface, the eye is sensitive to blast
21 injury, with ocular injuries in 4-28% of children following trauma related to combat or ERW
22 (13,16,36,38,39,42,45,53,79). In keeping with patterns of facial injury, an increased
23 prevalence of eye injury is associated with blast injuries compared to GSW (13% vs 3%)(11).
24 Landmines are often associated with multiple foreign bodies on the conjunctiva, cornea and
25 sclera, in addition to sight-threatening injuries such as enucleation or eye globe
26 perforation(41). Monocular enucleation was observed in 4%, while bilateral enucleation, and
27 hence blindness, was more common (14%)(41,79). When compared to adult victims of
28 landmines and cluster bombs, children have more eye injuries (14% vs 8%)(78) as well as
29 twice the prevalence of eye globe perforation (28% vs 14%)(43) and complete loss of vision
30 (21 vs 10%)(62). Without adequate support, both monocular and bilateral vision loss may
31 translate to developmental and educational deficiencies in the growing child.
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34 Facial and eye injuries are frequent following exposure to blasts, and should raise suspicion
35 of intracranial injury. Important are the social and education implications of these disfiguring
36 injuries in the growing child.
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38 39 **Torso Injuries** 40

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42 Following blast injury, trauma to the torso is common, varying from 12-46% between studies
43 (11,13,41,43,47-49,67,16-18,32,36,38-40) and peaking in 5-10 year olds(22,33). Er et al.'s
44 (43) study on civilian paediatric injuries during the Syrian Civil War noted that the abdomen
45 was less commonly injured compared to adults (12 vs 20%), while chest injury with
46 accompanying lung contusion was present in 51% of children with torso injuries, compared
47 to 35% in adults. Both chest and abdominal injuries from blast are typically classed as
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3 'severe'(18). Abdominal injuries accounted for 18-19% of injury specific deaths following
4 blast in the paediatric population, while chest injuries have been attributed to 8% of deaths in
5 the ED(16). Explanations for this susceptibility to severe and life threatening torso injuries
6 include a lack of body armour compared to adult combat victims and the observation that
7 children have flexible rib cages allowing greater damage to underlying structures without rib
8 fracture, contributing to the increase in lung contusion observed(32).
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14 When organ specific injuries were examined, blast was most likely to cause open
15 penetrating wounds of the bowel and intra-abdominal organs, affecting the small intestine in
16 over a third (34%) and the liver, spleen or pancreas in 36%(16,54,61). Where internal organ
17 damage was sustained, injury specific mortality almost doubled from 15 to 29%(63). These
18 injuries were frequently contaminated due to bowel rupture, requiring multiple procedures
19 and a high rate of antibiotic usage(57). The thinner abdominal walls, reduced intraabdominal
20 fat and larger solid organs relative to the body cavity increases likelihood of visceral damage
21 following penetrating trauma, while delayed signs of visceral damage support the role of
22 repeated examination and radiological input, even in the absence of external damage.
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29 In the context of total operative procedures performed, laparotomies comprised a significant
30 component of total surgical workload, encompassing 12-23% of all paediatric procedures
31 performed(25,58,92). Children were more likely to require laparotomies following combat
32 trauma compared to paediatric non-combat, and primarily blunt, abdominal trauma (13 vs
33 2%). Children in combat zones were also twice as likely to undergo laparotomies compared
34 to US service personnel (12% vs 6%)(68). In addition to the high prevalence of abdominal
35 injuries, children frequently swallow air when frightened or in pain, resulting in gastric
36 dilation. As well as increasing vomiting risk, this may erroneously suggest abdominal
37 injury(89) and lead to laparotomy. Despite this, Arafat et al(61) noted that only 8% of
38 laparotomies were negative, supporting the role of explorative laparotomies in penetrating
39 trauma following blasts.
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47 Compared to both adults and children in non-conflict settings, the blast injured child is more
48 likely to sustain injuries to the chest. While abdominal injuries are less frequent, they are
49 more likely to involve visceral damage and require operative management compared to adult
50 combat trauma.
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55 **Extremity injuries**

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57 Extremity injury is one of the defining features following blast related trauma. Extremity
58 injuries within conflict zones are observed in just under half of children (45%), its prevalence
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3 increasing in blast injuries (69%)(49), with a retrospective study finding 100% of traumatic
4 amputations and 96% of bone injuries to hand and foot were secondary to blast injuries(39).
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7 Studies describe extreme variation in the prevalence of upper limb injuries following blasts,
8 ranging from 6-74% (13,25,40,41,47,48,58,67,69,29,32,33,35-39), with the greatest upper
9 limb injury reported following UXO and cluster munition strike(41,44). Compared to adult and
10 particularly following ERW blast, children were more likely to sustain upper limb injuries
11 (62,67,70-73) with a corresponding increase of 150-300% requiring operative amputation,
12 typically at the level of the finger (37,66,71,72). Traumatic amputation of the upper limb was
13 common and limited to the hands in 44-94% of children sustaining upper limb injuries(38,41),
14 while trans-radial and trans-humeral amputation was less frequent (14-34%)(25,48) but were
15 more likely to be bilateral(79). Arm fractures necessitating surgical fixation were observed in
16 45%(29), while upper limb vasculature was commonly disrupted(17,32,48).
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24 Similarly, prevalence of lower limb injuries shows variation between studies on blast
25 affecting 25-86% of children(13,25,48,67,29,35-38,40,41,47), with landmine strikes
26 particularly associated with lower limb injury(35,37,41); 20-29% required operative
27 amputations, normally at the trans-tibial plane(37,38,79). Lower limb injuries were less
28 common in children compared to adults(62,70,72-74), with incidence lowest in 0-3 year
29 olds(22), while increasing in adolescents to mirror adults(62). Traumatic amputations were
30 less frequent compared to the upper limb, occurring in 14-35% of lower limb
31 injuries(25,41,48).
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38 Landmines drive debris, footwear and clothing upward between planes of the soft tissues
39 and bone, leading to degloving injuries of the leg, perineum and lower abdominal viscera, as
40 well creating serious potential for soft tissue and bone infection in the remaining limb(84,90).
41 While large bony defects of the lower limb are problematic in children(93), reconstruction
42 with limited shortening (<2 cm) has been associated with good outcomes, with the capability
43 for highly active growth plates to remodel and compensate for this (39,94). However, 75% of
44 new growth occurs in the distal femur and tibia growth plates, with the distal limb most prone
45 to explosive disruption(84).
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51 The long term physical, psychosocial and financial repercussions of amputation must not be
52 underestimated. Physical complications are greatest following TA and below knee
53 amputations, and include anterior and varus bowing, heterotopic ossification and osseous
54 overgrowth requiring operative or prosthetic revision(95). Overgrowth is particularly
55 problematic in younger patients (under 12 years), with 15% of patients sustaining
56 amputations requiring re-vision of their stump. Protracted phantom limb sensation (PLS) and
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phantom limb pain (PLP) is reported in over 50% of children following blast related amputation, similar to that seen in adult literature following blasts(96), yet over five times higher than in children requiring amputation following non-traumatic indications such as malignancy. Increased PLS has been reported in lower limb amputations, while PLP was increased in upper limb amputations (22,100). Social acceptance of the child amputee is culturally specific, with stigmatisation in certain cultures negatively impacting the child's psychological, social and educational status(97). While there is a paucity of outcome and long term costing studies in LMICs, the financial burden of prolonged rehabilitation and repeated revision of prosthesis on the children and host country's health system is likely to be considerable(97).

Like adults involved in blast trauma, older and adolescents children are prone to extremity injury, particularly of the upper limb, while infants and toddlers experience less extremity injuries. Limb injury causes diverse complications in the growing child with increased requirement for re-revision compared to adults.

Burn injuries

Multiple retrospective studies have noted that the majority of burns in children result from civilian mechanisms such as scalding, open fires and flash burns from household cooking fuels (15,16,46,98,99), while approximately 9-12% is the result of high-order explosives observed in combat blast modalities(46,99), less than observed in adult combat populations (52%)(100). Unlike civilian mechanisms however, blast-induced burns rarely occur in isolation, with multidimensional injuries playing a significant role in the child's prognosis(33,50,99). While post-mortem findings following the Syrian Civil War attributed only 0.5% of deaths being secondary to burns(63), conflict-related burn victims had higher mortality compared to non-conflict related burn victims (47% vs 3%)(98), and significantly greater than blast related burns in adult military populations (5%)(100). Severe burns following blasts were sustained in 30% of children, and fatal in 36-40%(18,40).

Creamer(38) noted the median age of burn victims as 6 years old. At this young age, the anatomical disproportionality of the child increases the total body surface area (TBSA), resulting in significant burn surface area (BuSA). Thus, approximately half of paediatric burns in conflict zones result in BuSA >15% (32,127), while 13% of children have BuSA exceeding 40%(127). A high BuSA exceeding 40% has been linked to myocardial damage and hypotension, making hemodynamic management challenging, while complications including nosocomial infection of the burn eschar and pneumonia are not uncommon(98).

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3 Within LMICs, protein loss and weight based fluid resuscitation is complicated by
4 malnourishment, while cold fluids may accentuate hypothermia(46).
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7 In conflict related burns, the head and neck are most frequently affected, potentially leading
8 to thermal inhalation injuries(50,99). Thermal inhalation injuries in paediatric victims are
9 difficult to assess, and clues to inhalational injuries such as increased respiratory rate may
10 be incorrectly interpreted in the context of physiological age discrepancies. In addition the
11 paediatric subglottis represents the narrowest section of the upper airway, and deteriorates
12 rapidly from burn-induced laryngeal oedema, especially in the context of failed intubation
13 attempts(101) leading to rapid oxygen desaturation. Between 21-33% of children were
14 identified as having inhalational injuries requiring pre-emptive or immediate intubation to
15 protect the airways(50,53), similar to that seen in adult combat casualties (26%)(100). Of this
16 paediatric cohort with inhalational injuries, 39% died(50), significantly greater than in adult
17 populations (4%)(100).
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26 Prognosticating factors noted for burns include increased time to presentation, prolonged
27 hospital length of stay and requirement for critical care input(98). This relates to the
28 resource-intensive management of the paediatric burns patient. Like adults, hospital length
29 of stay for burns patients are 2-3 times that of the general paediatric population(36,99), while
30 ICU requirements are increased, particularly in burns secondary to blast injuries(98,99).
31 Operative demands of paediatric burn victims are significant. Children aged 6 months to 3
32 years were between 4-14 times more likely than adults to require surgical input , reflecting
33 the significant burden of burns (39% of this cohort compared to 2-6% in adults(102)). While
34 other conditions may be treated by a single operation, burns often require serial
35 procedures(102), with an average 2 operations per patient. This creates a disproportionate
36 operative volume in both adults and paediatric patients compared to other surgical
37 emergencies(102). Burns induced by blast injuries require more escharotomies (27% vs 4%
38 $P<0.001$) and fasciotomies (67% vs 30% $P=0.002$) when compared to civilian burn
39 mechanisms(98).
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49 Additionally, the requirement for post-operative support and rehabilitation add to the
50 resource requirements. Children are rarely left without functional sequelae, with limited joint
51 mobility and impaired tactile sensation presenting significant future challenges for
52 rehabilitation(103), while high rates of psychological morbidity including suicidal ideation
53 have been reported in adolescents(104). Under-resourcing psychological and functional
54 rehabilitation will likely lead to high rates of morbidity and mortality(102). The degree to
55 which these services are available within conflict zones and LMICs is uncertain. Ethical
56 questions naturally arise when performing interventions where health systems are unlikely to
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3 address a child's long term needs. Examination of existing paediatric burn services within
4 zones of interest and longer term follow up of paediatric blast burn patients are required to
5 determine the problems and needs for this cohort.
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8 9 **Service provision**

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11 Relative to total admissions, paediatric victims affected by blasts constitute a
12 disproportionately large resource burden on operative workload, as well as intensive care
13 and hospital beds. Approximately 47-82% of paediatric blast victims require
14 surgery(22,33,36,58,61), particularly adolescents(22). The requirement for multiple operative
15 procedures were common in the paediatric cohort, especially in burn and orthopaedic
16 surgery due to the requirement for surgical revision (34-80% of children required ≥ 2
17 procedures(16,18,36,38-40,42,54); 25% required ≥ 4 procedures)(16). Operative
18 requirement was greatest in 9-14 year olds, requiring on average 5 procedures per patient,
19 prolonged ICU and hospital stay, while 0-3 year olds required the least operative
20 management(20). This study suggested the reduced requirement for operative input in 0-3
21 year olds may be due not only to the reduced burden of extremity injuries requiring repeated
22 debridement, but potentially because the equipment was inappropriate for this young cohort.
23 This is supported by observations that infants and young children aged 0-10 years old with
24 an Injury Severity Score ≥ 15 were 4x less likely to go to surgery compared to adults, while
25 adolescents (11-15 years) were 2x more likely to receive operative input(22).
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36 Multidisciplinary surgical services were required in 80% of patients, with orthopaedic, plastic,
37 general neurosurgical, ophthalmic and vascular surgeons often working in partnership(48).
38 Debridement and primary skin closure represented the most common procedure, in 35-
39 100% of studies(25,29,36-38,47,58,68), in keeping with shrapnel injuries leading to multiple
40 and frequently contaminated superficial injuries(29,47). Children are likely to do well with
41 thorough debridement, with well perfused tissues allowing optimal healing and scar
42 formation(39,94).
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48 Retrospective studies of US military medical treatment facilities (MTF) in Afghanistan have
49 found that while children comprised only 3-6% of their total admissions, this demographic
50 required approximately double the total bed spaces (7-11%)(14,19,53), and on average 3x
51 the length of stay (LOS) of coalition troops admitted over the same time period(14,68).
52 Approximately 40% of paediatric admissions required a LOS exceeding 7 days, while, in half
53 , the LOS exceeded 14 days(10,33). Spinella et al noted that while children aged 11-17 were
54 the greatest proportion of children occupying beds, <1 year old cohort had the longest
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3 stay(68). This contrasts with other studies finding young children <8 years old had the
4 shortest LOS, while children(8-14 years old) had the longest(14,18).
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8 A similar burden is observed in the intensive care unit (ICU), with between 20-45% children
9 requiring ICU admission(5,30,33,36,43,50,53,54,61), the majority following explosive or
10 ballistic trauma. Children were often younger (0-10 years old)(22), with one recent study
11 noting children aged <1 year and 1-4 years most often requiring admission (53 & 66%
12 respectively)(30). Children under 8 required a ICU LOS over twice that of children aged >8
13 years (52). Harris et al(5) noted that despite representing only 12% of admissions, children
14 occupied on average 35% of ICU beds, with a brief surge in numbers resulting in 100%
15 occupancy from children, the majority requiring ventilatory and ionotropic support. This
16 specialised service was often provided by non-paediatric experts, which could result in 2
17 healthcare providers per paediatric patient(5). Ventilatory equipment is often age specific,
18 and although multiple examples of ingenuity and adaptation of adult equipment exist(5,54),
19 children may overwhelm the unprepared MTF.
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27 One of the key challenges is providing sustainable health services in the host country. MTFs
28 may be capable of delivering exceptional paediatric care in the acute phase following blasts,
29 but recovery from morbidity is dependent on long term rehabilitation(94) normally provided
30 by the host country. Not only can this place exceptional strain on local health authorities, but
31 if provisions are not available, the child is likely to undergo a protracted decline(5,94).
32 Failures to secure recovery in the long term is likely to result in the limitations in observing
33 the Articles of the UNCRC, as listed in the Introduction to this review.
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40 Reasons for the high rate of admission and prolonged stay may be multifactorial. Admission
41 criteria for host nationals to a coalition MTF typically require threat to life, limb, or eyesight,
42 with resulting prolonged stay. Interestingly however, children with mild to moderate traumata
43 are three times more likely than adults to be admitted (22). This may reflect a lack of
44 certainty in initial assessment of injury severity from health practitioners unaccustomed to
45 dealing with children. Within conflict zones, rearwards evacuation of civilians is not always
46 possible, and health interventions such as ventilatory support may not be sustainable by
47 host countries without deterioration in service standards, leading to prolonged admission
48 until the child can be safely moved(5).
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55 Following up recovery is a recurring theme when exploring long term challenges of blast
56 injuries in children(6). Children are a complex cohort to monitor. Geographical displacement,
57 particularly in the context of a conflict, increases the likelihood of this vulnerable cohort being
58 lost to follow-up. This can impact not only the child's rehabilitation and coordination with local
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3 health authorities, but also cause difficulty in assessing long-term functional outcomes which
4 are needed to detect future health needs. Increasingly there is recognition of the need for
5 formalised trauma registries accessible in the host country, assisting the follow-up of this
6 vulnerable demographic(6,18,19,53).
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10 11 **Conclusion** 12

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14 This review has focused on research based on those child patients injured by blast primarily
15 (although not exclusively) in conflict zones in the Middle East and Afghanistan. Although
16 the papers under review were written by authors from a wide variety of nationalities and
17 professions that encounter paediatric blast injury and its effects, they all wrote in English for
18 journals which assumed a level of English fluency in their readership. Non-English
19 research, both written and published in non-English journals was outside the purview of the
20 study. The authors of the study sincerely hope that future work will be able to address this
21 by comparing research on paediatric blast injury done in settings and with study parameters
22 that may differ from those considered here. In doing so a truly global understanding of the
23 condition may be achieved, beyond our focus on today's conflict zones.
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31 Most paediatric blast injury is inflicted in these settings but is not exclusive to them. In Britain
32 in May 2017, a bomb detonated at the Manchester Arena killing 23 people and injuring 139,
33 most of whom were children. The attack placed a sudden and significant burden on medical
34 services in the city, which had no experience of paediatric blast injury in the 21st century, let
35 alone on this kind of scale.
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40 Wherever in the world they live, and whatever the circumstances of the explosion, the social
41 and anatomical profile of children makes them uniquely vulnerable to one of the most
42 complex and demanding trauma conditions that any medical professional or system can
43 treat. This paper has characterised paediatric blast as a diverse injury pattern, which must
44 be seen as distinct from its adult equivalent. This pattern should be fully understood from
45 point of wounding through the post-operative and rehabilitation phases of treatment. This
46 continuum approach would enable both better long-term care of the patient, and improved
47 support of medical systems bearing the intense burden of that care.
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53 It remains to be seen whether the monitoring of the long term effects of paediatric blast injury
54 in well-resourced environments is any better than that in areas of instability. Monitoring of
55 patient outcomes should be integrated with the monitoring of treatment so that relevant
56 practice and skills can be continually assessed. Thus the authors join with other
57 organisations concerned with the welfare of the world's children (such as the recently
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3 established BRANCH Consortium - *Bridging Research and Action in Conflict Settings for the*
4 *Health of Women and Children*) in calling for immediate action to fill the evidence and policy
5 gaps relating to child conflict injury and the interventions needed to improve its long term
6 outcomes.
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10 It has been our intention in conducting this review to provide specific technical medical detail
11 of one of the greatest horrors in our world today – that of the direct effects of war on children.
12 We hope it will be useful to everyone, from medical researchers to humanitarian
13 organisations, who seek to mitigate those effects, and secure the safety and wellbeing of
14 children wherever they grow up. It is not only coherence in treatment and understanding of
15 child blast injury that is required, it is a restatement of global commitment to the UN
16 Convention on the Rights of Child, so that today's horrors will not become those of
17 tomorrow.
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30 **Acknowledgments**

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32 The authors are grateful to Dr David Inwald for his detailed comments on this review.
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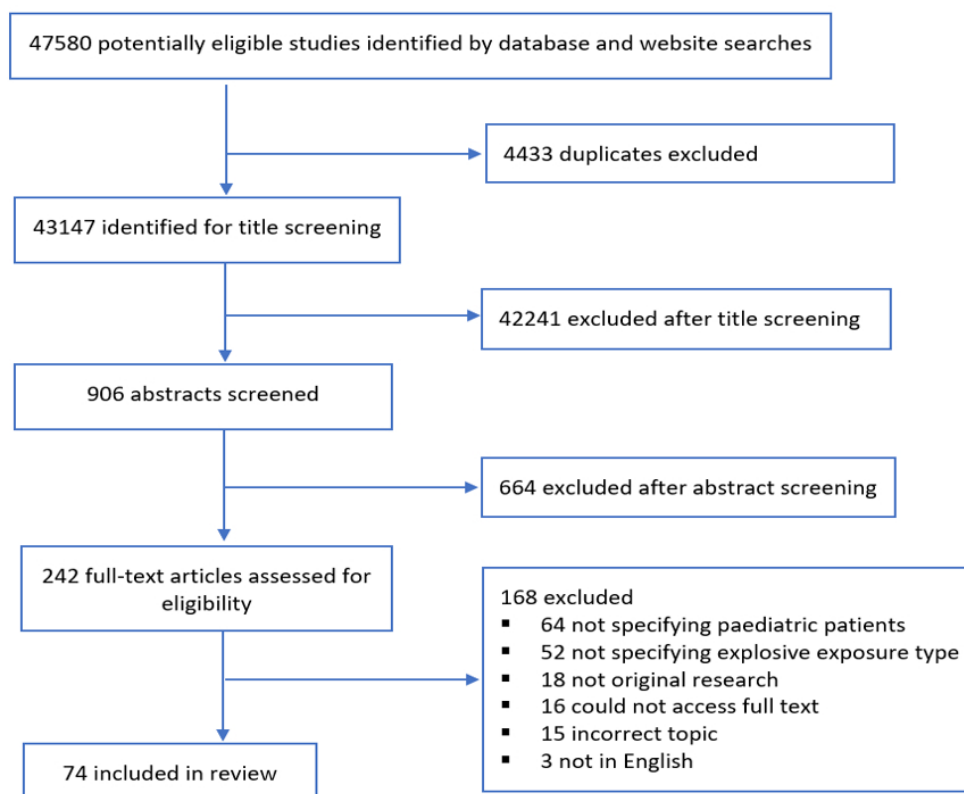
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