BMJ Paediatrics Open

Blast injuries in children: a mixed-methods narrative review

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To cite: Milwood Hargrave J, Pearce P, Mayhew ER, *et al*. Blast injuries in children: a mixed-methods narrative review. *BMJ Paediatrics Open* 2019;**3**:e000452. doi:10.1136/bmjpo-2019-000452

Received 15 February 2019
Revised 6 July 2019
Accepted 8 August 2019

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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-methods 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 a range of international specialists in the field.

Results Children affected by blast injuries are predominantly male and their injuries arise from explosive remnants of war, particularly unexploded ordinance. 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 with 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 highlight the importance of understanding the diverse injury patterns in order to optimise future service provisions in caring for this child blast survivor.

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 (HEs), either through explosive remnants of war (ERW) such as landmines and unexploded ordinance (UXO), 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 on the child through the blast overpressure 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 United Nations Convention on the Rights of the Child (UNCRC) seeks to secure both the safety and the well-being of all the world's children. The long-term consequences of conflict injury constitute 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] argued 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 explosive injuries in paediatric cohorts. By using all study designs, greater capture of relevant literature was achieved, although this meant the data were unsuitable for a formal systematic review. PubMed and Scopus (including Embase) were searched. Search terms including 'Paediatric' OR 'Pediatric' OR 'Child*' OR 'Children' AND 'Blast' OR 'Explosi*' OR 'Explosion' were used to capture potential studies. Articles had to be written in English and published before 16 December 2018. Studies involving adult and children were included, in addition to articles where the mechanism of injury was mixed. This decision was taken in order to accurately reflect the settings the studies represent, where victims in conflict zones are heterogeneous and subject to a variety of combat-related mechanisms. Studies were omitted if they did not specify explosive mechanisms or include children.

Children are defined as all humans under the age of 18 years (as specified by the UNCRC).[4] The heterogeneity and arbitrary nature of what defines a child is acknowledged, and studies often use individual definitions. Within this review, ages are defined; thus, <1 year are infants, 1–8 are young children, 9–13 are older children and 14–18 are adolescents.

Patient and public involvement

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

RESULTS

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

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] while children involved in conflict and ERW blast injuries were generally aged between 4 and 10 years old.[12 13] Perpetrators target busy areas such as restaurants and nightclubs which older children and adolescents might frequent,[10 11 14] while cultural factors within LMICs in these social areas result in a predominantly male cohort.[9 11 14–21] Similar gender findings 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).

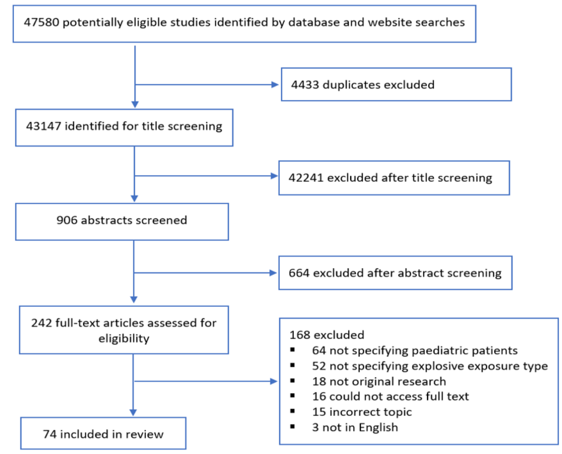

Figure 1 Study selection.

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.[22–30] It should be noted that statistics on prehospital mortality for children in conflict settings is generally an underestimation due to the difficulties in reporting and monitoring. It should be noted overall that there is limited statistical information available currently to researchers wherever they work with blast-injured children and that thus the percentages used in some of the papers they considered were unable to be supported with the full range of statistical confirmation. It is hoped that this review will provide focus for those organisations that seek to provide statistics on child conflict injuries, for instance, many explosive weapons observation groups do not or who are unable to distinguish between adults and children in their reporting.

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.[24 25 31–33] 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 with 30%–40% in adults.[27 30 34]

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

Table 1 The 26 studies using 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)[14]	2000–2004	Israel	Civilian	1155	Paediatric (8%) Adult (92%)	Suicide IEDs (100%)	Retrospective. National Trauma Registry	Injuries and mortality
Amir *et al* (2005)[10]	2000–2002	Israel	Civilian	148	Paediatric (100%)	IEDs/Shelling (66%) GSW (34%)	Retrospective. National Trauma Registry	Injuries and mortality
Bilukha *et al* (2015)[15]	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)[59]	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)[42]	2001–2011	Afghanistan Iraq	Military	128 582	Paediatric (6%) Adult (94%)	Non-combat (40%) IEDs/Shelling (38%) GSW (22%)	Retrospective. Military Trauma Registry	Injuries and mortality
Borgman *et al* (2015)[51]	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)[43]	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)[64]	2006–2008	Iraq	Military	25	Paediatric (100%)	IEDs/Shelling (72%) GSW (28%)	Retrospective. Military Trauma Registry	Injuries and mortality
Edwards *et al* (2012)[12]	2002–2012	Afghanistan Iraq	Military	4913	Paediatric (100%)	IEDs/Shelling (100%)	Retrospective. Military Trauma Registry	Injuries and mortality

Continued

Table 1 Continued

	Monitoring period	Location	Setting	Sample size	Population	Exposure	Study	Effect investigated
Edwards *et al* (2014)[96]	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)[44]	2002–2010	Afghanistan Iraq	Military	4928	Paediatric (100%)	IEDs/Shelling (100%)	Retrospective. Military Trauma Registry	Injuries and mortality
Hillman *et al* (2016)[97]	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)[16]	2000–2005	Israel	Civilian	837	Paediatric (14%) Adult (86%)	IEDs (100%)	Retrospective. National Trauma Registry	Injuries and mortality
Khan *et al* (2015)[17]	2010–2011	Pakistan	Civilian	103	Paediatric (16%) Adult (84%)	IEDs (100%)	Retrospective National Trauma Registry	Injuries and mortality
Kluger *et al* (2004)[18]	2000–2003	Israel	Civilian	906	Paediatric (7%) Adult (93%)	IEDs (100%)	Retrospective. National Trauma Registry	Injuries and mortality
McKechnie *et al* (2014)[35]	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)[98]	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)[38]	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)[99]	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)[82]	1996	USA	Civilian	66	Paediatric (100%)	IED (100%)	Retrospective. National Trauma Registry	Injuries and mortality

Continued

Table 1 Continued

	Monitoring period	Location	Setting	Sample size	Population	Exposure	Study	Effect investigated
Schauer *et al* (2018)[49]	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)[100]	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)[61]	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)[11]	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)[74]	2003–2009	Afghanistan Iraq	Military	176	Paediatric (100%)	IEDs/Shelling (59%) GSW (21%) Non-combat (20%)	Retrospective. Military Trauma Registry	Injuries and mortality

GSW, gunshot wound; IEDs, improvised explosive devices.

Table 2 The 26 studies using single-centre hospital-based case series

	Monitoring period	Location	Setting	Sample size	Population	Exposure	Study	Effect investigated
Al-Worikat *et al* (2001)[22]	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)[45]	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)[23]	1991	Kuwait	Civilian	152	Paediatric (12%) Adult (88%)	Landmines (100%)	Retrospective. Single-centre hospital-based case series	Injuries and mortality
Beitler *et al* (2006)[65]	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)[66]	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)[46]	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)[24]	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)[36]	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)[67]	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

Continued

Table 2 Continued

	Monitoring period	Location	Setting	Sample size	Population	Exposure	Study	Effect investigated
Fares *et al* (2013)[31]	2006–2011	Lebanon	Civilian	122	Paediatric (100%)	UXO (100%)	Retrospective. Single-centre hospital-based case series	Long term sequelae
Fares *et al* (2014)[71]	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)[90]	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)[68]	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)[69]	1991–1992	Croatia	Military	1211	Paedaitric (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)[70]	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)[93]	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)[75]	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

Continued

Table 2 Continued

	Monitoring period	Location	Setting	Sample size	Population	Exposure	Study	Effect investigated
Matos *et al* (2008)[48]	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)[62]	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)[78]	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)[60]	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)[101]	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)[80]	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)[47]	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)[13]	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)[102]	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

GSW, gunshot wound; IEDs, improvised explosive devices; UXO, unexploded ordinance.

Table 3 The eight studies using multicentre hospital-based case series

	Monitoring period	Location	Setting	Sample size	Population	Exposure	Study	Effect investigated
Arafat *et al* (2017)[79]	2012–2013	Syria	Civilian	324	Paediatric (18%) Adult (82%)	IEDs/Shelling (57%) GSW (43%)	Retrospective. Multicentre hospital-based case series	Injuries and mortality
Bendinelli *et al* (2009)[25]	2003–2006	Cambodia	Civilian	356	Paediatric (26%) Adult (74%)	Landmines (67%) UXO (33%)	Retrospective. Multicentre 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. Multicentre hospital-based mortuary case series	Mortality
Celikel *et al* (2015)[37]	2012–2014	Syria	Civilian	140	Paediatric (100%)	IEDs/Shelling (70%) GSW (14%) Other/Unknown (16%)	Retrospective. Multicentre hospital-based mortuary case series	Mortality
Gataa *et al* (2011)[77]	2005–2006	Iraq	Civilian	551	Paediatric (20%) Adult (80%)	IEDs (82%) GSW (18%)	Retrospective. Multicentre hospital-based case series	Injuries and mortality
Hanevik *et al* (2000)[83]	1991–1995	Eritrea	Civilian	248	Paediatric (63%) Adult (37%)	Landmines (100%)	Retrospective. Multicentre hospital-based case series	Injuries and mortality
Mirza *et al* (2013)[19]	2007–2011	Pakistan	Civilian	1142	Paediatric (6%) Adult (94%)	IEDs (100%)	Retrospective Multicentre hospital-based mortuary case series	Injuries and mortality
Spinella *et al* 2008[50]	2001–2007	Afghanistan Iraq	Military	1305	Paediatric (100%)	Trauma (Unspecified) (100%)	Retrospective. Multicentre hospital-based case series	Injuries and mortality

GSW, gunshot wound; IEDs, improvised explosive devices; UXO, unexploded ordinance .

Table 4 The 13 studies using community surveillance

	Monitoring period	Location	Setting	Sample size	Population	Exposure	Study	Effect investigated
Andersson *et al* (1995)[26]	1994–1995	Afghanistan Bosnia Cambodia Mozambique	Civilian	2100	Paediatric (100%)	Landmines (100%)	Retrospective. Community surveillance	Socioeconomic
Bilukha *et al* (2003)[27]	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)[55]	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)[28]	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)[29]	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)[56]	2008–2011	Nepal	Civilian	437	Paediatric (14%) Adult (76%)	IEDs (69%) Other/Unknown (31%)	Retrospective. Community surveillance	Injuries and mortality
Guerriero *et al* (2014)[20]	2013	USA	Civilian	11	Paediatric (100%)	IEDs (100%)	Prospective. Community surveillance	Long-term sequelae
Guha-Sapir *et al* (2018)[39]	2011–2016	Syria	Civilian	101 453	Paediatric (17%) Adult (83%)	Shelling/Air bombardment (57%) Other/Not specified (43%)	Retrospective. Community surveillance	Mortality
Hemmati *et al* (2015)[103]	1988–2013	Iran	Civilian	78	Paediatric (100%)	Landmines (100%)	Cross-section. Community surveillance	Long-term sequelae
Kinra *et al* (2003)[30]	1991–2000	Bosnia and Herzegovina	Civilian	4064	Paediatric (14%) Adult (86%)	Landmines (100%)	Retrospective. Community surveillance	Injuries and mortality
Mousavi *et al* (2015)[34]	2014	Iran	Civilian	78	Paediatric (100%)	Landmines (80%) UXO (20%)	Retrospective. Mixed-methods community surveillance	Long-term sequelae/ Injuries and mortality
Pat-Horenczyk *et al* (2007)[21]	2006	Israel	Civilian	695	Paediatric (100%)	IEDs (100%)	Retrospective. Mixed-methods community surveillance	Long-term sequelae
Poor Zamany Nejat *et al* (2016)[104]	2015	Iran	Civilian	41	Paediatric (100%)	Landmines (100%)	Retrospective. Mixed-methods community surveillance	Long-term sequelae

IEDs, improvised explosive devices; UXO, unexploded ordinance .

Table 5 The one study using grey literature

	Monitoring period	Location	Setting	Sample size	Population	Exposure	Study	Effect investigated
Guha-Sapir *et al* (2015)[40]	2011–2014	Syria	Civilian	78 769	Paediatric (16%) Adult (84%)	IEDs/Shelling (75%) GSW (25%)	Grey literature	Mortality

GSW, gunshot wound; IEDs, improvised explosive devices.

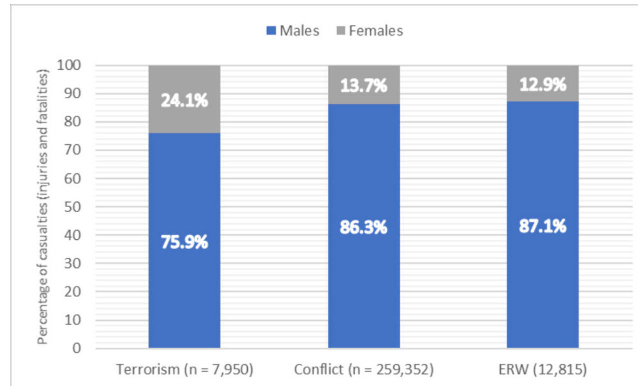

Figure 2 Gender differences in casualties following blast. ERW, explosive remnants of war.

exposure to ERWs through increased freedom to roam where such devices are present.[28 35–37] A lack of formal education impacts the child's ability to read warning signs; only 6%–22% of victims were aware ERWs were present,[21 38] and of these, only 0%–11% had received ERW risk education.[17 21 35 38]

Children are particularly vulnerable to wide-area explosives such as aerial bombardment and shelling, particularly in the primarily urbanised environments of modern conflicts. In the Syrian Civil War, three quarters of wide-area explosives were used in civilian residential areas that children frequent, with these mechanisms responsible for 82% of child deaths.[39 40]

The following section reviews what is known of mortality in children before reviewing injury types.

Mortality

Comparison of paediatric wartime mortality data is difficult as many studies do not differentiate mechanism of injury. Edwards *et al*'s[41] study on 4913 children between 2002 and 2010 presenting with blast injuries remains the single largest data set. The reported mortality rate of 8% matches well with the mortality rates of 6%–9% quoted in paediatric trauma deaths from Iraq and Afghanistan, although these studies displayed all trauma mechanisms as opposed to specifying blast trauma.[35 42–46] Between 2006 and 2013, Thompson *et al*[47] noted a mortality rate

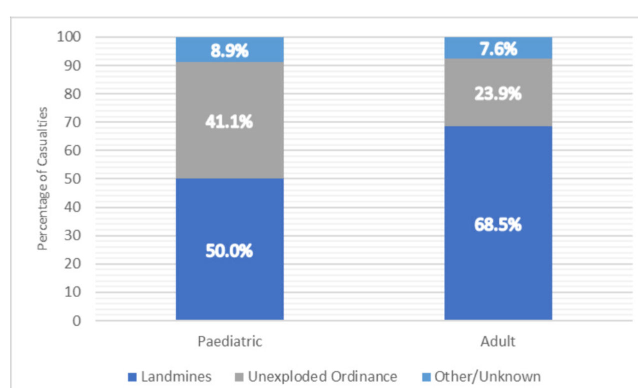

Figure 3 Percentage of casualties (injuries and fatalities) by specific modalities.

over double of that quoted by Edwards *et al* following paediatric blast injury in Afghanistan (18%). Operational tempo and the increasing use of IEDs have been hypothesised to underlie these discrepancies in mortality.[47]

Age-related variation in mortality has been described. Matos *et al* noted mortality was highest at 24% in young children (5–8 years old),[48] while Schauer *et al* and Spinella *et al* found greatest mortality in 0–4 years old.[49 50] Similarly, Borgman *et al* and Matos *et al* noted that children <8 years old had increased trauma mortality compared with 8–16 years old (10%–18% vs 4%–7%),[48 51] while Spinella *et al* noted a similar increase in mortality in young children (<6 years old) compared with 6–16 years old (11% vs 4%).[50] Few studies directly compare adult and paediatric mortality, and comparisons between studies are difficult due to methodological differences. What is common is that mortality in children following combat-related trauma is considerably higher than that of paediatric non-combat trauma (2%–3%)[52] and adult military combat casualties (1%–3%).[53 54]

A wide range of paediatric mortality is reported following mine strikes, ranging from 4% from 46%.[24–29 31 32 55 56] Shuker[57] suggested that approximately half of paediatric victims die within minutes of mine explosion, likely due to penetrating head injury, and catastrophic haemorrhage causing non-survivable injuries, in keeping with adult literature.[53 54] Time critical injuries following blasts may represent particular problems in LMICs, where prehospital evacuation chains may be protracted. Coupland nd Korver[58] noted that in 1991, only 14% of paediatric and adult ERW victims were admitted in less than 6 hours, while the majority (58%) were admitted between 6 and 24 hours and 28% presented after 24 hours. Even in recent conflicts, Bitterman *et al*[59] found <10% of children presented within 1 hour, with over a third presenting after 6 hours. Protracted evacuation of paediatric victims adds to blast mortality, reinforced by studies observing a 85%–91% mortality of children either at scene or en route to health facilities.[29 57]

Vascular injuries

Penetrating injuries occur in 38%–76% of blast-exposed children,[9 11 14 23 42 43 45 60] with incidence greater in older children aged 10–16 years old compared with 0–10 years old (65%–83% vs 47%–63%).[16 48] In keeping with penetrating injury patterns, vascular injury was observed in 3%–12% of children following blast trauma,[9 11 23 61] considerably higher compared with non-blast conflict trauma where vascular injury occurred in 0.6%–1% of paediatric victims.[9 14 18 61 62]

Vascular damage and subsequent haemorrhage following explosions have been identified as a significant cause of childhood fatalities, ranging from the primary cause of death in 21%–38% during the Syrian Civil War[37 63] to 63% following IED and suicide attacks in Pakistan,[19] while mortality rates following penetrating injuries in civilian settings are considerably lower (5%).[61] Extremity trauma was most highly associated with vascular injuries, with the majority of vascular injuries occurring in the lower limb (38%–58%) followed by the upper limbs (25%–28%).[61 64] This is in keeping with adult data where 54% of injuries were sustained to the extremities.[53] Despite its high prevalence, extremity vascular wounds confer reduced risk of death compared with vascular damage within the torso, attributed as the primary cause of death in 71% of paediatric deaths and conferring a fourfold increased risk of death compared with extremity vascular injuries.[61]

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

Head injuries

The prevalence of head injuries following blasts are diverse, ranging from 6% to 54%,[10–12 14 36 43 45 46 59 61 62 65–70] while adult combat data range from 16% to 29%.[53] This variation is due to the heterogeneous definitions of head injury described in these studies, with few studies differentiating between superficial scalp wounds, blunt traumatic brain injury (TBI) or penetrating TBI. Where head injuries were documented, TBI was recorded in 21%–62% of paediatric victims, of which 38%–39% were defined as penetrating.[11 69 71] Unsurprisingly, papers noted over double the incidence of paediatric penetrating head injury in blast trauma compared with mainly blunt civilian trauma (13% vs 6%), while the reverse was true in closed head injuries, with half the incidence of closed head injuries in blast injuries compared with civilian trauma (22% vs 44%).[9]

Cerebral haemorrhage and direct cranial damage following blast have been attributed as a leading cause of death in children, responsible for 46%–71% of fatalities.[23 45 65 67 72] Creamer[65] noted penetrating wounds to the head accounted for 44% of child deaths in the emergency department (ED), while open skull fractures with cerebral evisceration was documented in 88% of paediatric fatalities following the 1995 Oklahoma City bombings.[73] While penetrating head injuries undoubtedly carry high mortality, Woods *et al*[74] noted that eight children survived to hospital discharge despite penetrating head injuries deemed initially unsurvivable, suggesting such are not unequivocally fatal.

Er *et al*[67] noted that children were more likely to be injured in the head compared with adults (54% vs 40%) following aerial and shelling during the Syrian Civil War, while young children aged between 0 and 4 years old were more likely to undergo neurosurgical procedures compared with other ages,[44 75] 48% of which were craniectomies or craniotomies for penetrating brain injury, mainly secondary to IED blasts.[75] Suggested reasons for this increase may relate to anatomical predispositions, particularly in infants, such as large head to body ratios in addition to reduced skull rigidity,[16] as well as the relatively shorter distance from the head to ground-based ERW and IEDs compared with adults.[12 16 25 33 57]

There is a clear lack of studies investigating long-term outcomes following blast-associated head injuries. While significant cognitive, intellectual and functional sequelae arising from non-blast TBI (nbTBI) have been described, controversy exists as to whether nbTBI is analogous to blast-induced TBI,[76] and the paucity of paediatric data means this comparison is even more problematic.

A unifying message is that head injuries are associated with high morbidity and mortality in paediatric blast trauma, while the long-term consequences remain largely unknown. Head injuries are commonly penetrating compared with civilian practice, and increased operative demand in infants and toddlers for neurosurgical procedures may stretch medical service expertise.

Facial and ocular injuries

Blasts result in injury to the face in between 27% and 48% of paediatric victims, compared with 12% resulting from gunshot wound (GSW)[10 12 70] and 10% in adults.[53] Relative to other blast-related injuries, facial injuries in isolation are associated with reduced mortality.[12] However, Gataa and Muassa[77] noted that of the patients presenting with facial injuries, 29% had concomitant eye injury, 22% had TBI, while life-threatening facial bleeding occurred in 10% of patients. In addition to physical sequelae, facial injuries are associated with functional and psychological disorders stemming from stigmatisation of disfiguring injuries with implications for future social, economic and marital prospects.[77]

Despite only comprising 0.3% of the anterior body surface, the eye is sensitive to blast injury, with ocular injuries in 4%–28% of children following trauma related to combat or ERW.[34 36 43 45 59 62 65 66 71] In keeping with patterns of facial injury, an increased prevalence of eye injury is associated with blast injuries compared with GSW (13% vs 3%).[10] Landmines are often associated with multiple foreign bodies on the conjunctiva, cornea and sclera, in addition to sight-threatening injuries such as enucleation or eye globe perforation.[24] Monocular enucleation was observed in 4%, while bilateral enucleation, and hence blindness, was more common (14%).[24 34] Compared with adult victims of landmines and cluster bombs, children have more eye injuries (14% vs 8%)[30] as well as twice the prevalence of eye globe perforation (28% vs 14%)[67] and complete loss of vision (21% vs 10%).[25] 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% to 46% between studies[10 12 19 24 43 45 46 59 61 64–70] and peaking in 5–10 year olds.[11 16] Er *et al*'s[67] study on civilian paediatric injuries during the Syrian Civil War noted that the abdomen was less commonly injured compared with adults (12% vs 20%), while chest injury with accompanying lung contusion was present in 51% of children with torso injuries, compared with 35% in adults. Both chest and abdominal injuries from blast are typically classed as 'severe'.[12] 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.[43] Explanations for this susceptibility to severe and life-threatening torso injuries include a lack of body armour compared with 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.[61]

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%.[43 78 79] 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.[80] The thinner abdominal walls, reduced intraabdominal fat and larger solid organs relative to the body cavity increase the 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.[35 47 81] Children were more likely to require laparotomies following combat trauma compared with paediatric non-combat, and primarily blunt, abdominal trauma (13$ vs 2%). Children in combat zones were also twice as likely to undergo laparotomies compared with US service personnel (12% vs 6%).[50] In addition to the high prevalence of abdominal injuries, children frequently swallow air when frightened or in pain, resulting in gastric dilation. As well as increasing vomiting risk, this may erroneously suggest abdominal injury[57] and lead to laparotomy. Despite this, Arafat *et al*[79] noted that only 8% of laparotomies were negative, supporting the role of explorative laparotomies in penetrating trauma following blasts.

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

Extremity injuries

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 increasing in blast injuries (69%),[70] with a retrospective study finding 100% of traumatic amputations and 96% of bone injuries to hand and foot were secondary to blast injuries.[66]

Studies describe extreme variation in the prevalence of upper limb injuries following blasts, ranging from 6% to 74%,[11 19 22–24 26 35 45–47 59 61 65 66 68 69 82] with the greatest upper limb injury reported following UXO and cluster munition strike.[24 31] Compared with adult and particularly following ERW blast, children were more likely to sustain upper limb injuries[19 25 27–29 55] with a corresponding increase of 150%–300% requiring operative amputation, typically at the level of the finger.[23 28 55 83] Traumatic amputation of the upper limb was common and limited to the hands in 44%–94% of children sustaining upper limb injuries,[24 65] while transradial and transhumeral amputation was less frequent (14%–34%)[35 69] but were more likely to be bilateral.[34] Arm fractures necessitating surgical fixation were observed in 45%,[82] while upper limb vasculature was commonly disrupted.[61 64 69]

Similarly, prevalence of lower limb injuries shows variation between studies on blast affecting 25%–86% of children,[19 22–24 35 45 46 59 65 68 69 82] with landmine strikes particularly associated with lower limb injury[22–24] ; 20%–29% required operative amputations, normally at the transtibial plane.[23 34 65] Lower limb injuries were less common in children compared with adults,[25 27–29 56] with incidence lowest in 0–3 year olds,[16] while increasing in adolescents to mirror adults.[25] Traumatic amputations were less frequent compared with the upper limb, occurring in 14%–35% of lower limb injuries.[24 35 69]

Landmines drive debris, footwear and clothing upward between planes of the soft tissues and bone, leading to degloving injuries of the leg, perineum and lower abdominal viscera, as well creating serious potential for soft tissue and bone infection in the remaining limb.[33 58] While large bony defects of the lower limb are problematic in children,[84] reconstruction with limited shortening (<2 cm) has been associated with good outcomes, with the capability for highly active growth plates to remodel and compensate for this.[66 85] However, 75% of new growth occurs in the distal femur and tibia growth plates, with the distal limb most prone to explosive disruption.[33]

The long-term physical, psychosocial and financial repercussions of amputation must not be underestimated. Physical complications are greatest following TA and below knee amputations, and include anterior and varus bowing, heterotopic ossification and osseous overgrowth requiring operative or prosthetic revision.[86] Overgrowth is particularly problematic in younger patients (under 12 years), with 15% of patients sustaining amputations requiring re-vision of their stump. Protracted phantom limb sensation (PLS) and phantom limb pain (PLP) are reported in over 50% of children following blast-related amputation, similar to that seen in adult literature following blasts,[87] 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.[16 88] Social acceptance of the child amputee is culturally specific, with stigmatisation in certain cultures negatively impacting the child's psychological, social and educational status.[89] 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.[89]

Like adults involved in blast trauma, older and adolescent 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 with 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,[43 51 90–92] while approximately 9%–12% is the result of HEs observed in combat blast modalities,[90 92] less than observed in adult combat populations (52%).[88] Unlike civilian mechanisms, however, blast-induced burns rarely occur in isolation, with multidimensional injuries playing a significant role in the child's prognosis.[11 92 93] While postmortem 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 with non-conflict related burn victims (47% vs 3%),[91] and significantly greater than blast related burns in adult military populations (5%).[88] Severe burns following blasts were sustained in 30% of children and fatal in 36%–40%.[12 46]

Creamer[65] 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, 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 haemodynamic management challenging, while complications including nosocomial infection of the burn eschar and pneumonia are not uncommon.[91] Within LMICs, protein loss and weight-based fluid resuscitation is complicated by malnourishment, while cold fluids may accentuate hypothermia.[90]

In conflict-related burns, the head and neck are most frequently affected, potentially leading to thermal inhalation injuries.[92 93] 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 attempts[72] leading to rapid oxygen desaturation. Between 21% and 33% of children were identified as having inhalational injuries requiring pre-emptive or immediate intubation to protect the airways,[62 93] similar to that seen in adult combat casualties (26%).[88] Of this paediatric cohort with inhalational injuries, 39% died,[93] significantly greater than in adult populations (4%).[88]

Prognosticating factors noted for burns include increased time to presentation, prolonged hospital length of stay and requirement for critical care input.[91] This relates to the resource-intensive management of the paediatric burns patient. Like adults, hospital length of stay (LOS) for burns patients are two to three times that of the general paediatric population,[45 92] while intensive care unit (ICU) requirements are increased, particularly in burns secondary to blast injuries.[91 92] Operative demands of paediatric burn victims are significant. Children aged 6 months to 3 years were between 4 and 14 times more likely than adults to require surgical input, reflecting the significant burden of burns (39% of this cohort compared with 2%–6% in adults[73]). While other conditions may be treated by a single operation, burns often require serial procedures,[73] with an average of two operations per patient. This creates a disproportionate operative volume in both adults and paediatric patients compared with other surgical emergencies.[73]Burns induced by blast injuries require more escharotomies (27% vs 4% p<0.001) and fasciotomies (67% vs 30% p=0.002) when compared with civilian burn mechanisms.[91]

Additionally, the requirement for postoperative support and rehabilitation adds 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,[94] while high rates of psychological morbidity including suicidal ideation have been reported in adolescents.[95] Under-resourcing psychological and functional rehabilitation will likely lead to high rates of morbidity and mortality.[73] 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,[11 16 45 47 79] particularly adolescents.[16] The requirement for multiple operative procedures was 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[12 36 43 45 46 65 66 78]; 25% required ≥4 procedures).[43] Operative requirement was greatest in 9–14 year olds, requiring on average five procedures per patient, prolonged ICU and hospital stay, while 0–3 year olds required the least operative management.[44] 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 four times less likely to go to surgery compared with adults, while adolescents (11–15 years) were two times more likely to receive operative input.[16]

Multidisciplinary surgical services were required in 80% of patients, with orthopaedic, plastic, general neurosurgical, ophthalmic and vascular surgeons often working in partnership.[69] Debridement and primary skin closure represented the most common procedure, in 35%–100% of studies,[23 35 45 47 50 65 68 82] in keeping with shrapnel injuries leading to multiple and frequently contaminated superficial injuries.[68 82] Children are likely to do well with thorough debridement, with well-perfused tissues allowing optimal healing and scar formation.[66 85]

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%),[42 62 96] and on average three times the LOS of coalition troops admitted over the same time period.[42 50] Approximately 40% of paediatric admissions required an LOS exceeding 7 days, while in half, the LOS exceeded 14 days.[11 14] Spinella *et al* noted that while children aged 11–17 years old were the greatest proportion of children occupying beds, <1-year-old cohort had the longest stay.[50] This contrasts with other studies finding young children<8 years old had the shortest LOS, while children (8–14 years old) had the longest.[12 42]

A similar burden is observed in the ICU, with between 20% and 45% children requiring ICU admission,[5 11 45 49 62 67 78 79 93] the majority following explosive or ballistic trauma. Children were often younger (0–10 years old),[16] with one recent study noting children aged <1 year and 1–4 years most often requiring admission (53%–66% respectively).[49] Children under 8 years old required an ICU LOS over twice that of children aged >8 years.[48] Harris *et al*[5] noted that despite representing only 12% of admissions, children occupied on average 35% of ICU beds, with a brief surge in numbers resulting in 100% occupancy from children, the majority requiring ventilatory and ionotropic support. This specialised service was often provided by non-paediatric experts, which could result in two healthcare providers per paediatric patient.[5] Ventilatory equipment is often age specific, and although multiple examples of ingenuity and adaptation of adult equipment exist,[5 78] children may overwhelm the unprepared MTF.

One of the key challenges is providing sustainable health services in the host country. MTFs may be capable of delivering exceptional paediatric care in the acute phase following blasts, but recovery from morbidity is dependent on long-term rehabilitation[85] normally provided by the host country. Not only can this place exceptional strain on local health authorities, but if provisions are not available, the child is likely to undergo a protracted decline.[5 85] Failure to secure recovery in the long term is likely to result in the limitations in observing the Articles of the UNCRC, as listed in the Introduction to this review.

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.[16] 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 12 62 96]

CONCLUSION

This review has focused on research based on those child patients injured by blast primarily (although not exclusively) in conflict zones in the Middle East and Afghanistan. Although the papers under review were written by authors from a wide variety of nationalities and professions that encounter paediatric blast injury and its effects, they all wrote in English for journals which assumed a level of English fluency in their readership. Non-English research, both written and published in non-English journals, was outside the purview of the study. The authors of the study sincerely hope that future work will be able to address this by comparing research on paediatric blast injury done in settings and with study parameters that may differ from those considered here. In doing so, a truly global understanding of the condition may be achieved, beyond our focus on today's conflict zones.

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 postoperative 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.

It remains to be seen whether the monitoring of the long-term effects of paediatric blast injury in well-resourced environments is any better than that in areas of instability. Monitoring of patient outcomes should be integrated with the monitoring of treatment so that relevant practice and skills can be continually assessed. Thus, the authors join with other organisations concerned with the welfare of the world's children (such as the recently established BRANCH Consortium—*Bridging Research and Action in Conflict Settings for the Health of Women and Children*) in calling for immediate action to fill the evidence and policy gaps relating to child conflict injury and the interventions needed to improve its long-term outcomes.

It has been our intention in conducting this review to provide specific technical medical detail of one of the greatest horrors in our world today—that of the direct effects of war on children. We hope it will be useful to everyone, from medical researchers to humanitarian organisations, who seek to mitigate those effects, and secure the safety and well-being of children wherever they grow up. It is not only coherence in treatment and understanding of child blast injury that is required, it is a restatement of global commitment to the UNCRC, so that today's horrors will not become those of tomorrow.

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

Contributors JMH was responsible for the analysis of the data and the writing of the main body of the work. AB and ERM made substantial contributions to the concept of the work. AB supervised the design and analysis of the bioengineering material used by JMH. PP and JMH acquired and sorted the medical journal articles for relevance to the field. PP oversaw the analysis for tables and figures

and substantially contributed to the general supervision of the overall project. ERM contributed the Introduction and Conclusion text material. AB, ST, PP and ERM gave extensive critical revisions for important intellectual and technical content and approved the final version of the draft. All authors have agreed to be accountable for all aspects of the work. ERM is the corresponding author and is responsible for submission.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests None declared.

Patient consent for publication Not required.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement There are no data in this work.

REFERENCES

1. Frost A, Boyle P, Autier P, *et al*. The effect of explosive remnants of war on global public health: a systematic mixed-studies review using narrative synthesis. *Lancet Public Health* 2017;2:e286–96.
2. Wolf SJ, Bebarta VS, Bonnett CJ, *et al*. Blast injuries. *The Lancet* 2009;374:405–15.
3. Champion HR, Holcomb JB, Young LA. Injuries from explosions: physics, biophysics, pathology, and required research focus. *J Trauma* 2009;66:1468–77.
4. UNICEF. United Nations Convention on the Rights of the Child [Internet], 1989. Available: https://downloads.unicef.org.uk/wp-content/uploads/2010/05/UNCRC_united_nations_convention_on_the_rights_of_the_child.pdf?_ga=2.85767705.181858325.1504263661-1041319099.1504263661 [Accessed 1 Sep 2017].
5. Harris C, McNicholas J. Paediatric intensive care in the field Hospital. *J R Army Med Corps* 2009;155:157–9.
6. Bull A, Mayhew E, Reavley P, *et al*. Comment Paediatric blast injury : challenges and priorities. *Lancet child Adolesc Heal* 2018;4642:20–1.
7. Bree S, Wood K, Nordmann G, *et al*. The paediatric transfusion challenge on deployed operations. *J R Army Med Corps* 2010;156(Suppl_4):S361–4.
8. Diana G, Msn R, Sally K, *et al*. Using system change as a method of performance / quality improvement 2010.
9. Aharonson-Daniel L, Waisman Y, Dannon YL, *et al*. Epidemiology of terror-related versus non-terror-related traumatic injury in children. *Pediatrics* 2003;112:e280.
10. Amir LD, Aharonson-Daniel L, Peleg K, *et al*. The severity of injury in children resulting from acts against civilian populations. *Ann Surg* 2005;241:666–70.
11. Waisman Y, Aharonson-Daniel L, Mor M, *et al*. The impact of terrorism on children: a two-year experience. *Prehosp Disaster Med* 2003;18:242–8.
12. Edwards MJ, Lustik M, Eichelberger MR, *et al*. Blast injury in children: an analysis from Afghanistan and Iraq, 2002-2010. *J Trauma Acute Care Surg* 2012;73:1278–83.
13. Walker N, Russell R, Hodgetts T. British military experience of pre-hospital paediatric trauma in Afghanistan. *J R Army Med Corps* 2010;156:150–3.
14. Aharonson-Daniel L, Klein Y, Peleg K. Suicide bombers form a new injury profile. *Ann Surg* 2006;244:1018–23.
15. Bilukha OO, Leidman EZ, Sultan A-SS, *et al*. Deaths due to intentional explosions in selected Governorates of Iraq from 2010 to 2013: prospective surveillance. *Prehosp Disaster Med* 2015;30:586–92.
16. Jaffe DH, Peleg K. Terror explosive injuries: a comparison of children, adolescents, and adults. *Ann Surg* 2010;251:138–43.
17. Khan I, Khan N, Naeem R, *et al*. Bomb blast injuries: an exploration of patient characteristics and outcome using Pakistan national emergency departments surveillance (Pak-NEDS) data. *BMC Emerg Med* 2015;15 Suppl 2:S7.
18. Kluger Y, Peleg K, Daniel-Aharonson L, *et al*. The special injury pattern in terrorist bombings. *J Am Coll Surg* 2004;199:875–9.
19. Mirza FH, Parhyar HA, Tirmizi SZA. Rising threat of terrorist bomb blasts in karachi – a 5-year study. *J Forensic Leg Med* 2013;20:747–51.
20. Guerriero RM, Pier DB, de Gusmão CM, *et al*. Increased pediatric functional neurological symptom disorders after the Boston marathon bombings: a case series. *Pediatr Neurol* 2014;51:619–23.
21. Pat-Horenczyk R, Abramovitz R, Peled O, *et al*. Adolescent exposure to recurrent terrorism in Israel: posttraumatic distress and functional impairment. *American Journal of Orthopsychiatry* 2007;77:76–85.
22. Al-Worikat AF. Landmine amputees referred to the royal medical services - Jordan. *Prosthet Orthot Int* 2001;25:108–12.
23. Bajec J, Gang RK, Lari AR. Post Gulf War explosive injuries in liberated Kuwait. *Injury* 1993;24:517–20.
24. Can M, Yildirimcan H, Ozkalipci O, *et al*. Landmine associated injuries in children in turkey. *J Forensic Leg Med* 2009;16:464–8.
25. Bendinelli C. Effects of land mines and unexploded ordnance on the pediatric population and comparison with adults in rural Cambodia. *World J Surg* 2009;33:1070–4.
26. Andersson N, da Sousa CP, Paredes S. Social cost of land mines in four countries: Afghanistan, Bosnia, Cambodia, and Mozambique. *BMJ* 1995;311:718–21.
27. Bilukha OO, Brennan M, Woodruff BA. Death and injury from Landmines and Unexploded ordnance in Afghanistan. *JAMA* 2003;290:650–3.
28. Bilukha OO, Brennan M, Anderson M. The lasting legacy of war: epidemiology of injuries from Landmines and Unexploded ordnance in Afghanistan, 2002–2006. *Prehosp Disaster Med* 2008;23:493–9.
29. Bilukha OO, Laurenge H, Danee L, *et al*. Injuries and deaths due to victim-activated improvised explosive devices, landmines and other explosive remnants of war in Nepal. *Injury Prevention* 2011;17:326–31.
30. Kinra S, Black ME. Landmine related injuries in children of Bosnia and Herzegovina 1991-2000: comparisons with adults. *J Epidemiol Community Health* 2003;57:264–5.
31. Fares Y, Ayoub F, Fares J, *et al*. Pain and neurological sequelae of cluster munitions on children and adolescents in South Lebanon. *Neurol Sci* 2013;34:1971–6.
32. Surrency AB, Graitcer PL, Henderson AK. Key factors for civilian injuries and deaths from exploding landmines and ordnance. *Injury Prevention* 2007;13:197–201.
33. Watts HG. The consequences for children of explosive remnants of war: land mines, unexploded ordnance, improvised explosive devices, and cluster bombs. *J Pediatr Rehabil Med* 2009;2:217–27.
34. Mousavi B, Soroush MR, Masoumi M, *et al*. Epidemiological study of child casualties of landmines and unexploded ordnances: a national study from Iran. *Prehosp Disaster Med* 2015;30:472–7.
35. Mckechnie PS, Wertin T, Parker P, *et al*. Pediatric surgery skill sets in role 3: the Afghanistan experience. *Mil Med* 2014;179:762–5.
36. El H, Agard E, Dot C. Cephalic region war injuries in children : Experience in French NATO hospital in Kabul Afghanistan. *Injury* 2018;49:1703–5.
37. Çelikel A, Karbeyaz K, Kararslan B, *et al*. Childhood casualties during civil war: Syrian experience. *J Forensic Leg Med* 2015;34:1–4.
38. Neff LP, Cannon JW, Morrison JJ, *et al*. Clearly defining pediatric massive transfusion: cutting through the FOG and friction with combat data. *J Trauma Acute Care Surg* 2015;78:22–8.
39. Guha-Sapir D, Schlüter B, Rodriguez-Llanes JM, *et al*. Patterns of civilian and child deaths due to war-related violence in Syria: a comparative analysis from the violation documentation center dataset, 2011–16. *The Lancet Global Health* 2018;6:e103–10.
40. Guha-Sapir D, Rodriguez-Llanes JM, Hicks MH, *et al*. Civilian deaths from weapons used in the Syrian conflict. *BMJ* 2014;2015:1–5.
41. Edwards MJ, Lustik M, Eichelberger MR, *et al*. Blast injury in children. *J Trauma Acute Care Surg* 2012;73:1278–83.
42. Borgman M, Matos RI, Blackbourne LH, *et al*. Ten years of military pediatric care in Afghanistan and Iraq. *J Trauma Acute Care Surg* 2012;73(6 Suppl 5):S509–S513.
43. Creamer KM, Edwards MJ, Shields CH, *et al*. Pediatric wartime admissions to US military combat support hospitals in Afghanistan and Iraq: learning from the first 2,000 admissions. *J Trauma* 2009;67:762–8.
44. Edwards MJ, Lustik M, Carlson T, *et al*. Surgical interventions for pediatric blast injury: an analysis from Afghanistan and Iraq 2002 to 2010. *J Trauma Acute Care Surg* 2014;76:854–8.
45. Arul GS, Reynolds J, DiRusso S, *et al*. Paediatric admissions to the British military Hospital at cAMP Bastion, Afghanistan. *Annals* 2012;94:52–7.
46. Coppola CP, Leininger BE, Rasmussen TE, *et al*. Children treated at an Expeditionary military hospital in Iraq. *Arch Pediatr Adolesc Med* 2006;160:972–6.

47. Thompson DC, Crooks RJ, Clasper JC, *et al*. The pattern of paediatric blast injury in Afghanistan. *J R Army Med Corps* 2017:jramc-2017-000795.
48. Matos RI, Holcomb JB, Callahan C, *et al*. Increased mortality rates of young children with traumatic injuries at a US army combat support hospital in Baghdad, Iraq, 2004. *Pediatrics* 2008;122:e959–66.
49. Schauer SG, Hill GJ, Naylor JF, *et al*. Emergency department resuscitation of pediatric trauma patients in Iraq and Afghanistan. *Am J Emerg Med* 2018:1–5.
50. Spinella PC, Borgman MA, Azarow KS. Pediatric trauma in an austere combat environment. *Crit Care Med* 2008;36(Suppl):S293–S296.
51. Borgman MA, Matos RI, Spinella PC. Isolated pediatric burn injury in Iraq and Afghanistan*. *Pediatric Critical Care Medicine* 2015;16:e23–7.
52. Regional K, Regional O, Florida I. Comparison of Outcomes for Pediatric Trauma at Different Types of Trauma Centers : The Unresolved Mystery 2016:1054–8.
53. Owens BD, Kragh JF, Wenke JC, *et al*. Combat wounds in operation Iraqi freedom and operation enduring freedom. *J Trauma* 2008;64:295–9.
54. Eastridge BJ, Salinas J, Wade CE, *et al*. Hypotension is 100 MM Hg on the battlefield. *Am J Surg* 2011;202:404–8.
55. Bilukha OO, Brennan M, Anderson M, *et al*. Seen but not heard: injuries and deaths from Landmines and Unexploded ordnance in Chechnya, 1994–2005. *Prehosp Disaster Med* 2007;22:507–12.
56. Bilukha OO, Becknell K, Laurenge H, *et al*. Fatal and non-fatal injuries due to intentional explosions in Nepal, 2008-2011: analysis of surveillance data. *Confl Health* 2013;7:5.
57. Shuker ST. Effect of biomechanism mine explosion on children: craniofacial injuries and management. *J Craniofac Surg* 2013;24:1132–6.
58. Coupland RM, Korver A. Injuries from antipersonnel mines: the experience of the International Committee of the red cross. *BMJ* 1991;303:1509–12.
59. Bitterman Y, Benov A, Glassberg E, *et al*. Role 1 pediatric trauma care on the Israeli–Syrian Border—First year of the humanitarian effort. *Mil Med* 2016;181:849–53.
60. Pannell D, Poynter J, Wales P, *et al*. Factors affecting mortality of pediatric trauma patients encountered in Kandahar, Afghanistan. *Can J Surg* 2015;58:S141–S145.
61. Villamaria CY, Morrison JJ, Fitzpatrick CM, *et al*. Wartime vascular injuries in the pediatric population of Iraq and Afghanistan: 2002–2011. *J Pediatr Surg* 2014;49:428–32.
62. McGuigan R, Spinella PC, Beekley A, *et al*. Pediatric trauma: experience of a combat support hospital in Iraq. *J Pediatr Surg* 2007;42:207–10.
63. Celikel A, Karaarslan B, Demirkiran DS, *et al*. A series of civilian fatalities during the war in Syria. *Ulus Travma Acil Cerrahi Derg* 2014;20:338–42.
64. Dua A, Via KC, Kreishman P, *et al*. Early management of pediatric vascular injuries through humanitarian surgical care during U. *S. military operations. In: Journal of Vascular Surgery* 2013:695–700.
65. Beitler AL, Wortmann GW, Hofmann LJ, *et al*. Operation enduring freedom: the 48th combat support hospital in Afghanistan. *Mil Med* 2006;171:189–93.
66. Bertani A, Mathieu L, Dahan J-L, *et al*. War-Related extremity injuries in children: 89 cases managed in a combat support hospital in Afghanistan. *Orthopaedics & Traumatology: Surgery & Research* 2015;101:365–8.
67. Er E, Ş K, Güler S, *et al*. American Journal of emergency medicine analyses of demographical and injury characteristics of adult and pediatric patients injured in Syrian civil war ☆ 2017;35:82–6.
68. Hinsley DE, Rosell PAE, Rowlands TK, *et al*. Penetrating missile injuries during asymmetric warfare in the 2003 Gulf conflict. *Br J Surg* 2005;92:637–42.
69. Hodalić Z, Svagelj M, Sebalj I, *et al*. Surgical treatment of 1,211 patients at the Vinkovci General Hospital, Vinkovci, Croatia, during the 1991-1992 Serbian offensive in East Slavonia. *Mil Med* 1999;164:803–8.
70. Inwald DP, Arul GS, Montgomery M, *et al*. Management of children in the deployed intensive care unit at cAMP Bastion, Afghanistan. *J R Army Med Corps* 2014;160:236–40.
71. Fares Y, Fares J, Gebeily S. Head and facial injuries due to cluster munitions. *Neurol Sci* 2014;35:905–10.
72. Sharma R, Parashar A. Special considerations in paediatric burn patients. *Indian J Plast Surg* 2010;43:43–50.
73. Stewart BT, Trelles M, Dominguez L, *et al*. Surgical burn care by Médecins sans Frontières-Operations center Brussels. *Journal of Burn Care & Research* 2016;37:e519–24.
74. Woods KL, Russell RJ, Bree S, *et al*. The pattern of paediatric trauma on operations. *J R Army Med Corps* 2012;158:34–7.
75. Klimo P, Ragel BT, Scott WH, *et al*. Pediatric neurosurgery during operation enduring freedom. *J Neurosurg* 2010;6:107–14.
76. Rosenfeld JV, Ford NL. Bomb blast, mild traumatic brain injury and psychiatric morbidity: a review. *Injury* 2010;41:437–43.
77. Gataa IS, Muassa QH. Patterns of maxillofacial injuries caused by terrorist attacks in Iraq: retrospective study. *Int J Oral Maxillofac Surg* 2011;40:65–70.
78. Nordmann GR. Paediatric anaesthesia in Afghanistan: a review of the current experience. *J R Army Med Corps* 2010;156(Suppl_4):S323–6.
79. Arafat S, Alsabek MB, Ahmad M, *et al*. Penetrating abdominal injuries during the Syrian war: patterns and factors affecting mortality rates. *Injury* 2017;48:1054–7.
80. Terzić J, Mestrovic J, Dogas Z, *et al*. Children war casualties during the 1991-1995 wars in Croatia and Bosnia and Herzegovina. *Croat Med J* 2001;42:156–60.
81. Ramasamy A, Hinsley DE, Edwards DS, *et al*. Skill sets and competencies for the modern military surgeon: lessons from UK military operations in southern Afghanistan. *Injury* 2010;41:453–9.
82. Quintana DA, Jordan FB, Tuggle DW, *et al*. The spectrum of pediatric injuries after a bomb blast. *J Pediatr Surg* 1997;32:307–11.
83. Hanevik K, Kvåle G. Landmine injuries in Eritrea. *BMJ* 2000;321.
84. Franke A, Hentsch S, Bieler D, *et al*. Management of soft-tissue and bone defects in a local population: plastic and reconstructive surgery in a deployed military setting. *Mil Med* 2017;182:e2010–20.
85. Nordmann GR, McNicholas JJ, Templeton PA, *et al*. Paediatric trauma management on deployment. *J R Army Med Corps* 2011;157(3 Suppl 1):S334–S343.
86. Eichelberger MR. Pediatric surgery and medicine for hostile environments. *J Pediatr Surg* 2011;46:1683 p.
87. Article O. The experience of phantom limb pain in patients with combat-related traumatic amputations. *Arch Phys Med Rehabil* 2008.
88. Kauvar DS, Wolf SE, Wade CE, *et al*. Burns sustained in combat explosions in operations Iraqi and enduring freedom (OIF/OEF explosion burns). *Burns* 2006;32:853–7.
89. Cummings D. Prosthetics in the developing world: a review of the literature. *Prosthet Orthot Int* 1996;20:51–60.
90. Gurney I. Paediatric casualties during OP TELIC. *J R Army Med Corps* 2004;150:270–2.
91. Buyukbese S, Budeyri A. ScienceDirect Mortality risk factors in war-related pediatric burns : A comparative study among two distinct populations. *Burns* 2018:1–18.
92. Peleg K, Aharonson-Daniel L, Michael M, *et al*. Patterns of injury in hospitalized terrorist victims. *Am J Emerg Med* 2003;21:258–62.
93. Jeevaratnam JA, Pandya AN. One year of burns at a role 3 medical treatment facility in Afghanistan. *J R Army Med Corps* 2014;160:22–6.
94. Zeitlin REK, Järnberg J, Somppi EJ, *et al*. Long-Term functional sequelae after paediatric burns. *Burns* 1998;24:3–6.
95. Gautam S, Gupta ID, Batra L, *et al*. Psychiatric morbidity among victims of bomb blast. *Indian J Psychiatry* 1998;40:41–5.
96. Edwards MJ, Lustik M, Burnett MW, *et al*. Pediatric Inpatient Humanitarian Care in Combat: Iraq and Afghanistan 2002 to 2012. *J Am Coll Surg* 2014;218:1018–23.
97. Hillman CM, Rickard A, Rawlins M, *et al*. Paediatric traumatic cardiac arrest: data from the joint theatre trauma registry. *J R Army Med Corps* 2016;162:276–9.
98. Naylor JF, April MD, Roper JL, *et al*. Emergency department imaging of pediatric trauma patients during combat operations in Iraq and Afghanistan. *Pediatr Radiol* 2018;48:620–5.
99. Patregnani JT, Borgman MA, Maegele M, *et al*. Coagulopathy and shock on admission is associated with mortality for children with traumatic injuries at combat support hospitals*. *Pediatric Critical Care Medicine* 2012;13:273–7.
100. Smith JE, Kehoe A, Harrisson SE, *et al*. Outcome of penetrating intracranial injuries in a military setting. *Injury* 2014;45:874–8.
101. Pearce P. Preparing to care for paediatric trauma patients. *J R Army Med Corps* 2015;161(Suppl 1):i52–5.
102. Armed US. Pediatric trauma experience in a combat support hospital in eastern Afghanistan over 10 months. *2010 to* 2013;2011.
103. Hemmati MA, Shokoohi H, Masoumi M, *et al*. Mental health disorders in child and adolescent survivors of post-war landmine explosions. *Mil Med Res* 2015;2.
104. Poor Zamany Nejatkermany M, Modirian E, Soroush M, *et al*. Phantom limb sensation (PLS) and phantom limb pain (PLP) among young Landmine amputees. *Iran J Child Neurol* 2016;10:42–7.