Analysis of 983 civilian blast and ballistic casualties and the generation of a template of injury burden: An observational study

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Summary

Background Terrorism and armed conflict cause blast and ballistic casualties that are unusual in civilian practice. The immediate surgical response to mass casualty events, with civilians injured by these mechanisms, has not been systematically characterised. Standardising an approach to reacting to these events is challenging but is essential to optimise preparation for them. We aimed to quantify and assesses the surgical response to blast and ballistic injuries managed in a world-class trauma unit paradigm.

Methods This was an observational study conducted at the UK-led military Medical Treatment Facility, Camp Bastion, Afghanistan from original theatre log-book entries between Nov 5, 2009, and Sept 21, 2014; a total of 10,891 consecutive surgical cases prospectively gathered by surgical teams were catalogued. Patients with combatant status/wearing body-armour to various degrees including interpreters were excluded from the study. Civilian casualties that underwent primary trauma surgery for blast and ballistic injuries were included (n=983). Surgical activity was analysed as a rate per 100 casualties, and patients were grouped according to adult vs. paediatric and ballistic vs. blast injury mechanisms to aid comparison.

Findings The three most common surgical procedures for civilian blast injuries were debridement, amputation, and laparotomy. For civilian ballistic injuries, these were debridement, laparotomy and vascular procedures. Blast injuries generated more amputations in both adults and children compared to ballistic injuries. Blast injuries generated more removal of fragmentation material compared to ballistics injuries amongst adult casualties. Ballistic injuries lead to more chest drain insertions in adults. As a rate per 100 casualties, adults injured by blast underwent significantly more debridement (63·5); temporary skeletal stabilisation (13·2) and vascular procedures (12·8) compared to children (43·4, z=4·026, p=0·00007; 5·7, z=2·230, p=0·022; 4·9, z=2·468, p=0·014). Adults injured by ballistics underwent significantly more debridement (63·4); chest drain (12·3) and temporary skeletal fixation procedures (11·4) compared to children (50·0, z=2·058, p=0.040, p<0·05; 2·9, z=2·283, p=0.0230; 2·9, z=2·131, p=0.034 respectively). By comparison, children injured by ballistics underwent significantly more removal of fragmentation and ballistic materials (20·6) when compared to adults (7·7, z=−3·234; p=0.001).

Interpretation This is the first evidence-based, template of the immediate response required to manage civilians injured by blast and ballistic mechanisms. The template presented can be applied to similar conflict zones and to prepare for terror attacks on urban populations.

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Keywords: Civilian; Blast; Ballistic; Trauma; Surgery; Explosion; Treatment; War; Terror attacks; Template; Injury

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Research in context

Evidence before this study

A comprehensive review of the available literature was performed (scope search) to identify similar studies, and any additional surgical databases relevant to this study. The following search terms were used: "surgery OR surgical OR surgical training" AND "procedure OR procedures OR skill set OR intervention OR interventions" AND "Afghanistan" AND "role 3" AND "paediatric OR civilian". The database MEDLINE was continuously searched from Jan 1996 up until July 9, 2022 using the Ovid interface. This was combined with a thorough search, using direct terminology of PubMed and The Cochrane Database of Systematic Reviews.

Added value of this study

This paper represents the first quantification of the immediate surgical response to civilians injured by blast and ballistic weapons and the surgical ramifications of these on surgical interventions. The database created for the purposes of this study represents the largest complete consecutive dataset of surgical interventions from any contemporary conflict. Through analysis, a way of anticipating the number of surgical procedures (e.g. amputations, laparotomies etc.) necessary to be performed in future mass casualty blast/ballistic events, per 100 casualties is described.

Implications of all the available evidence

This paper presents the best available evidence-based template of injury burden and the surgical response required to attend these types of mass casualty events (MCE). In this way, these data can be used to better understand the immediate surgical response, to allocate resources, theatres and staff in major trauma events. These stratified frequency tables enable Emergency Preparedness, Resilience and Response (EPRR) planning for future acts of terror, industrial events and comparable conflicts using these wounding mechanisms.

Introduction

The rise in terror attacks directed at civilians has presented a unique challenge for healthcare professionals globally.[1] The future of armed conflicts is likely to be typified by prolonged evacuation chains, fewer surgeons, more austere environments and exaggerated timelines for casualty evacuation as we see in the Ukraine.[2] Civilian trauma surgeons do not see blast injuries routinely and may have limited experience with ballistic injuries.[3–7] Though blast and ballistic injuries are uncommon in times of peace, they are common in warzones, including the use of cluster bombs in the Ukraine.[8] Urban hospitals experience new kinds of injuries in war since blast injuries are typified by the polytrauma nature of injury, affecting multiple body regions with devastating effect, especially mangled extremities, whilst ballistic injuries produce cavities in tissue depending on the velocity and rate of energy they enter the tissue from the projectile source.[9,10]

The ballistic and blast wounds experienced in war are very different to traditional Gun Shot Wounds (GSW). The wounds are caused by projectiles and fragments from exploding munitions which send energized fragments into bodies causing catastrophic damage. Porta et al., (2013) report that 30% of US surgeons deployed to Iraq and Afghanistan performed procedures they hadn't done before. It is clear that there is a paucity of data to help address this important issue.[9,11] In accordance with Geneva conventions, civilian casualties were brought to Camp Bastion, Afghanistan. This non-body-armour wearing cohort included casualties with potential co-morbid conditions and presented a unique challenge to the surgeon and are generalisable to civilians injured by these mechanisms across the world. The immediate surgery carried out on the local population affected by conflict and its impact on the surgical provision has not yet been fully analysed. This study we hope provides potential surgeons with a heads-up list of the multiple surgical skills that a single surgeon or surgical team should possess when faced with a single blast or ballistic casualty in the context of a similar war zone or act of terror.

Unfortunately, due to the stochastic nature of terror attacks and limitations within conflicts, collecting coherent datasets has been challenging. In addition, translating findings from a resource limited warzone to resource rich peace-time healthcare systems can be difficult.

The dataset described here is the largest record of primary surgical interventions carried out on civilian casualties injured from blast and ballistics during an armed conflict, in a paradigm of effectively a peace-time major trauma centre setting. The surgery carried out on civilians affected by conflict and how this need may contribute to, or change, the surgical skills required has not been fully analysed.[2,6,12] Previous attempts have been made, however these primarily focus on the description of injury patterns, as opposed to the surgical ramifications of these on surgical interventions.

There is a paucity in comparable studies available since few available datasets include the latter half of the conflict in Afghanistan, as studied in this cohort. Previous attempts have been made to outline the surgical impact of civilian casualties on surgical provision. Such studies, however, primarily focus on the description of injury patterns, mechanisms of injury, and numbers of casualties. Ramasamy et al., (2010) classified the surgical procedures carried out in a two-year period (n=1668) by surgical speciality, and Schwab (2015) commented that it matched the American experience.[2,5,6] However, surgery on civilians was not delineated from combatants in describing suggested surgical skills sets and since analysis and data was centred around admissions, it was Emergency Medicine focused as well as limited by the number of data-points and narrow time periods analysed. Secondary take-back operations were not excluded from other studies (Jacobs et al 2012 n=299; Mckechnie et al 2014, n=766).[5,12] In addition, such studies described the civilian experience but also included non-combat related surgeries e.g. RTA and follow-up procedures. They are therefore limited in their scope and ability to characterise the surgical interventions performed, or the continuum of care required for future conflicts, or terror attacks caused by blast/ballistic mechanisms.

Since the present study focuses only on primary emergent trauma surgery, we present the first evidence-based surgical requirement for civilians injured by blast and ballistics. When we combine this with failings in the organisation of trauma care in England which are well described in the NCEPOD 2007 report "Trauma, who cares? we feel this study provides a tool to ensure both training and EPRR planning are informed as well as possible.[13]

The scenario in Afghanistan represented a unique situation where a state-of-the-art trauma hospital was deployed to an active warzone. During the conflict, some blast and ballistics civilian casualties were managed from the point of wounding to discharge by coalition forces in a state-of-the-art healthcare paradigm. This unique situation has allowed analysis of injury patterns, surgical skillsets required, types of surgery, numbers of operations and outcomes to be collected. Casualty nationality data were used as a proxy to examine the surgical activity for a population not wearing protective body armour (civilians). Compared to other civilian nations, those in our cohort may have had worse pre-morbid status perhaps given the limitations and accessibility of primary care within Afghanistan at the time of the conflict. However, this would not influence the injuries and or surgical provision sustained which is the focus of the present study. Our findings are therefore translatable to the civilian context of future conflicts and Mass Casualty Events (MCE) globally. As blast injuries increasingly occur in peacetime, the surgical template proposed first here is no-longer confined to the military or armed conflicts. Through analysis, the most effective surgical response for situations where high numbers of blast and ballistic casualties occur can be better determined.

Methods

Database

The database consists of the entirety of surgical cases of casualties treated in the UK-led field surgical hospital in Afghanistan between November 5, 2009, and the end of formal operations in Afghanistan, September 21, 2014. The database contains data on 10,891 individual surgical cases and 20,266 surgical procedures recorded in electronic format for analysis. Bias was avoided by searching sequentially as follows: 10891 cases, 8388 of which recorded demographics and 2676 were civilian casualties, therefore 2503 surgical cases are missing from the analysis and these would have been made up of civilians and combatants, who can be considered to be missing at random.

The present study focused specifically on the data from 983 individual civilian patients that underwent primary blast/ballistic trauma surgery. Given the minimal degree of missing data, a complete case population was used within each analysis.

Ethics and Review Board Statement: The Defence Medical Services (DMS) approves this research under the auspices of the Academic Department of Military Surgery and Trauma (ADMST) (MOD Research and Ethics Committee (MODREC) communication dated April 27 2017). Informed consent was waived given the retrospective and anonymised nature of the database.

Study design, patient identification and mechanism of injury

Individual surgical cases were categorised and analysed by casualty, nationality and mechanism of injury. Cases were selected for analysis based on mechanism of injury [blast and Gun Shot Wound (GSW)]; operation type (immediate vs. secondary), and demographics (civilian casualties, and paediatric casualties age <16 year). Blast or explosions included Improvised Explosive Devices (IED), mortar, and grenade. All other injury mechanisms and conditions were excluded. Secondary cases (i.e., surgery consequent to the immediate surgery) were also excluded from analysis. Bias was further addressed as we felt it appropriate to exclude combatants and interpreters as they wore varying degrees of body armour, which impacted on injury patterns, surgical need, and case fatality rates (manuscript in preparation).[14] Whilst it would definitely assist planners to provide the same template for the combatant (body-armour-wearing) cohort of our dataset – we felt that including this analysis (manuscript in preparation) would detract from the focus of the present work which focuses on the humanitarian surgical provision, since civilians are predominantly the first casualties of conflicts or terror related attacks, as an example, 2/3 of Ukrainian civilians remain in Ukraine.

Statistical analysis

The study size was determined by the number of eligible patients included in the database. First we characterised the wounding patterns by analysing body regions operated on. We then itemised the most common surgical procedures performed depending on the wounding mechanism to develop a template for anticipatingthe surgical response and lastly carried out comparative statistical analysis to define the differences between surgical interventions caused by different mechanisms of

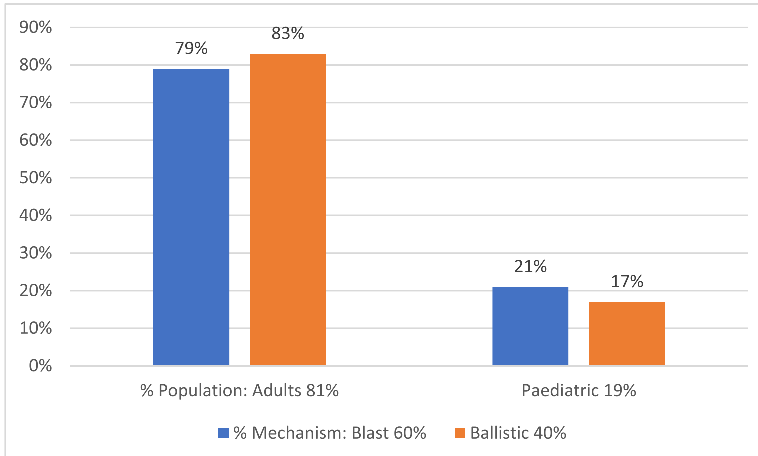

Figure 1. Patient groupings by Injury.

Proportion of total casualties (*n*=983) per mechanism of wounding. Of immediate surgery on civilian casualties, Blast and Ballistics accounted for 60% and 40% of wounding respectively [BLAST *n*=590; GSW *n*=393]. As a percentage of population, Adults accounted for 81% and Paediatric 19% of casualties [Adults: BLAST *n*=468; GSW 325; Paediatric: BLAST *n*=122; GSW *n*=68].

injury and performed on adults compared to paediatric casualties. All the data were entered into the Excel spreadsheet and analysed to determine the significance of various parameters. Statistical significance was expressed as a two-sided p value of <0.05, calculated using the two proportion z-test. Based on guidance provided in Newcombe 1998 we estimate confidence intervals for the difference in proportions using a method based on Wilson's score (method 10 of [Newcombe 1998]). Reported confidence intervals relate to the difference in two proportions. Intervals that include 0 are deemed non-significant at the 95% level.[15]

Role of the funding source

The funder of the study had no role in the study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all of the data in the study, compiled the database for analysis, and had final responsibility for the decision to submit for publication.

Results

Patient characteristics

Between November 5, 2009, and the end of formal British operations in Helmand province, September 21, 2014, we screened 10891 cases. The study included 983 civilian blast and ballistic casualties that received immediate surgery for their injuries (983/8388, 12%). For blast injuries, 468 were adult (79%) and 122 were paediatric (21%) (see Figure 1). For ballistic injuries, 325 were adult (83%) and 68 were paediatric (17%) (see Figure 1). As a percentage by population 81% were adults (*n*=793) and 19% were paediatric (*n*=190) (Figure 1) and as a percentage by mechanism 60% were blast (*n*=590) and 40% were ballistic (*n*=393) (Figure 1). None of the trauma casualties were female; just 12 female civilian casualties were recorded in our dataset (*n*=10,891), all of which were not trauma related, but rather emergency surgeries such as appendectomy or caesarean section. (8 adult, 4 paediatric).

Wounding characteristics

We show injury patterns for blast, ballistic trauma and the differences between childs and adult casualties in Tables 1a–4a.

Adult blast casualties suffered significantly more head (26·5%), abdomen (43·6%) and upper (42·9%) and lower extremity (51·1%) trauma compared to adult ballistic casualties (Table 1a Body Map: 8·0%, z=6·542, p=0.0000; 31·7%, z=3·383; p=0.0008; 28·9%, z=4·012, p=0.00007 and 40·0%, z=3·082, p=0.002). Civilian adults wounded by ballistics suffered significantly more chest trauma compared to blast (28·0%) (Table 1a Body map: 18·2%, z=−3·265; p=0.002).

Paediatric casualties injured by blast suffered significantly more upper (33·6%) and lower (54·1%) extremity trauma when compared to ballistic wounding (Table 2a Body map: 11·8%, z=3·292, p=0.001; 38·2%, z=2·202, p=0.038).

Paediatric blast casualties suffered significantly more head (36·9%) trauma compared to adults Table 3a Body map: 26·5%, z-2·263; p=0.024).

We compared the wounding patterns between adult and paediatric casualties wounded by ballistics and found that adults suffered significantly more upper extremity trauma (28·9%) but children suffered more head (29·4%) and abdominal trauma (60·3%) (Table 4a Body map: 11·8%, z=2·926, p=0.004; 8%, z=−4·992; p=0.0000; 31·7%, z=−4.451, p=0.00001).

Regions commonly affected	Percentage body regions injured by blast % n=468	Percentage body regions injured by ballistics n=325	CI of difference in proportions	z-value and p-value
Head	26·5	8·0	0·01–0·06	z=6·542; p=0·0000 p<0·001
Neck	3·8	6·2	−0.03–0·01	z=−1·557p=0·120; p>0·05
Chest	18·2	28·0	−0·09–0·01	z=−3·265; p=0·002 p<0.01
Abdomen	43·6	31·7	−0·05–0·04	z=3·383; p=0·0008 p<0·001
Perineum	3·6	1·8	−0·01–0·02	z=1·495; p=0·136 p>0·05
Junctional	7·9	4·6	−0·02–0·02	z=1·848; p=0·065 p>0·05
Lower extremity	51·1	40·0	−0·06–0·03	z= 3·082; p=0·002 p<0·05
Upper extremity	42·9	28·9	−0·04–0·04	z=4·012; 0·00007 p<0·001

***Table 1a*: Body map Blast and Ballistic Adult Wounding Patterns.**
Adult wounding patterns for adults injured by blast and ballistic weapons (n=793).

	BLAST n=468 Rate per 100 blast casualties	GSW n=325 Rate per 100 GSW casualties	CI of difference in proportions	z-value and p-value
Debridement	63·5	63·4	−0.11–0·01	z=0·029; p=0·977 p>0·05
Amputation	28·2	4·6	0.02–0.07	z=8·407; p=0·0000 p<0.001
Laparotomy	22·2	24·0	−0·07–0·01	z=−0·593; p=0·554 p>0.05
Removal of fragmentation or ballistic materials	17·6	7·7	−0·01–0·04	z=4·007; p=0·00007 p<0·001
Temporary skeletal stabilisation	13·2	11·4	−0·04–0·02	z=0·755; p=0·451 p>0.05
Vascular procedures	12·8	11·7	−0·04–0·02	z=0·463; p=0·643 p>0.05
Chest drain	7·7	12·3	−0·05–0·00	z=−2·164; p=0·030 p<0.05
Fasciotomy	6.0	6·5	−0·03–0·01	z=−0·287; p=0·774 p>0.05
Thoracotomy	2·4	3·9	−0·03–0·04	z=−1·215; p=0·225 p>0.05
Flaps/skin graft/reconstruction	1·3	0·8	−0·01–0·04	z=0·665; p=0·506 p>0.05
Burns	0·9	0.0	−0·01–0·04	z=1·715; p=0·087 p>0.05
Sternotomy	0·9	1·2	−0·02–0·03	z=−0·413; p=0·680 p>0.05
Airway procedures	0·2	0·3	−0·02–0·03	z=−0·282; p=0·778 p>0.05

***Table 1b*: Standardised surgical response to adult trauma casualties.**
Rate of surgical procedures per 100 adult blast and ballistic injured casualties. Adult blast and ballistic jcasualties n=793 (Figure 1).

Regions commonly affected	Percentage body regions injured by blast n=122	Percentage body regions injured by ballistics n=68	CI difference in proportions	z-value and p-value
Head	36·9	29·4	−0.32–0.00	z=1·045, p=0·298 p>0·05
Neck	2·5	1·5	−0.08–0.05	z=0·456, p=0·649 p>0·05
Chest	23·8	19·1	−0.26–0.03	z=0·748, p=0·456 p>0·05
Abdomen	52·5	60·3	−0.63–0.33	z=−1·037, p=0·302 p>0·05
Perineum	4·1	2·9	−0.10–0.05	z=0·422, p=0·674 p>0·05
Junctional	9·0	4·4	−0.1–0.09	z=1·165, p=0·247 p>0·05
Lower extremity	54·1	38·2	−0.32–0.02	z=2·102, p=0·038 p<0·05
Upper extremity	33·6	11·8	−0.05–0.23	z=3·292, p=0·001 p<0·01

***Table 2a*: Body Map Blast and Ballistic Paediatric Wounding Patterns.**
Body Map Table 2: Paediatric wounding patterns for children injured by blast and ballistic weapons (n=190).

Surgical characteristics

The five surgeries most frequently performed on adult blast casualties were: debridement, amputation, laparotomy, removal of fragmentation or ballistic materials, and temporary skeletal stabilization (Figure 2) and for ballistics: debridement, laparotomy, chest drain insertion, vascular procedures, and temporary skeletal stabilisation (Figure 2).

	BLAST n=122 Rate per 100 blast casualties	GSW n=68 Rate per 100 GSW casualties	CI difference in proportions	z-value and p-value
Debridement	43·4	50·0	−0.58−0.26	z=−0·875; p=0·383 p>0.05
Amputation	27·9	1·5	0.11−0.31	z=4·497; p=0·00002 p<0.001
Laparotomy	26·2	35·3	−0.50−0.18	z=−1·319; p=0·189 p>0.05
Removal of fragmentation or ballistic materials	16·4	20·6	−0.34−0.06	z=−0·724; p=0·471 p>0.05
Chest drain	8·2	2·9	−0.07−0.10	z=1·441 p=0·152 p>0.05
Temporary skeletal stabilisation	5·7	2·9	−0.09−0.07	z=0·874; p=0·383 p>0.05
Vascular procedures	4·9	10·3	−0.25−0.3	z=−1·414; p=0·160 p>0.05
Thoracotomy	3·3	4·4	−0.14−0.2	z=0·385; p=0·700 p>0.05
Fasciotomy	2·5	2·9	−0.11−0.03	z=-0·024; p=0·869 p>0.05
Sternotomy	1·6	1·5	−0.09−0.04	z=0·053; p=0·958 p>0.05
Burns	0·8	0		[a]
Flaps/skin graft/reconstruction	0·8	0		[a]
Airway procedures	0	0		NA

***Table 2b*: Standardised surgical response to paediatric trauma casualties.**

Rate of surgical procedures per 100 paediatric blast and ballistic injured casualties. Paediatric blast and ballistic casualties n=190.

[a] proportions too small for analysis.

Regions commonly affected	Percentage body regions injured by blast % n=468	Percentage body regions injured by blast n=122	CI difference in proportions	z-value and p-value
Head	26·5	36·9	−0.30−0.18	z−2·263; p=0·024 p<0·05
Neck	3·8	2·5	−0.06−0.01	z=0·693, p=0·488 p>0·05
Chest	18·2	23·8	−0.25−0.10	z=−1·394, p=0·164 p>0·05
Abdomen	43·6	52·5	−0.46−0.27	z=−1·758, p=0·080 p>0·05
Perineum	3·6	4·1	−0.08−0.01	z=−0·260, p=0·795 p>0·05
Junctional	7·9	9·0	−0.13−0.02	z=−0·396,p=0·692 p>0·05
Lower extremity	51.1	54·1	−0.46−0.26	z=−0·591, p=0·555 p>0·05
Upper extremity	42·9	33·6	−0.29−0.12	z=1·860, p=0·063 p>0·05

***Table 3a*: Body Map Adult vs. Paediatric Blast Wounding Patterns.**

Body Map Table 3: Wounding patterns for adults compared to paediatric casualties injured by blast (n=590).

	BLAST n=468 Rate per 100 blast casualties	BLAST n=122 Rate per 100 blast casualties	CI difference in proportions	z-value and p-value
Debridement	63·5	43.4	−0.34−0.15	4·026; p=0·00007 p<0·001
Amputation	28·2	27.9	−0.27−0.11	0.046; p=0·948 p>0·05
Laparotomy	22·2	26·2	−0.27−0.11	−0.0935; p=0·350 p>0·05
Removal of fragmentation or ballistic materials	17·6	16·4	−0.18−0.05	0.312; p=0·755 p>0·05
Temporary skeletal stabilisation	13·2	5·7	−0.08−0.01	2.230; p=0·022 p<0·05
Vascular procedures	12·8	4·9	−0.07−0.02	2.468; p=0·014 p<0·05
Chest drain	7·7	8·2	−0.12−0.02	−0.183; p=0.855 p>0·05
Fasciotomy	6.0	2·5	−0.06 -0.01	1.540; p=0·124 p>0·05
Thoracotomy	2·4	3·3	−0.07−0.00	−0.558; p=0·577 p>0·05
Flaps/skin graft/reconstruction	1·3	0·8	−0.04−0.01	0.452; p=0·651 p>0·05
Burns	0·9	0·8	[a]	[a]
Sternotomy	0·9	1·6	[a]	[a]
Airway procedures	0·2	0	[a]	[a]

***Table 3b*: Standardised Surgical response to adult vs paediatric blast casualties.**

Rate of surgical procedures per 100 adult blast casualties compared to paediatric blast casualties. Civilians underwent primary emergent trauma surgery for blast (n=590) (Figure 2; Figure 3).

[a] Proportions are not significantly different.

Regions commonly affected	Percentage body regions injured by ballistics n=325	Percentage body regions injured by ballistics n=68	CI difference in proportions	z-value and p-value
Head	8·0	29·4	−0.59−0.33	z=−4·992; p=0.000; p<0·001
Neck	6·2	1·5	−0.08−0.02	z=1·561, p=0.119; p>0·05
Chest	28.0	19.1	−0.36−0.11	z=1·513, p=0.131; p>0·05
Abdomen	31·7	60·3	−0.96−0.75	z=−4.451, p=0.00001; p<0·001
Perineum	1·8	2·9	−0.13−0.01	z=−0·591; p=0.555, p>0·05
Junctional	4·6	4·4	−0.15−0.01	z=0·072; p=0.943, p>0·05
Lower extremity	40·0	38·2	−0.63−0.36	z=0·276; p=0.783, p>0·05
Upper extremity	28·9	11·8	−0.23−0.01	z=2·926, p=0.004; p<0·01

***Table 4a*: Body Map Adult vs. Paediatric Ballistic Wounding Patterns.**
Body Map: Wounding patterns for adults compared to paediatric casualties injured by ballistics (n=393).

	GSW n=325 Rate per 100 adult GSW casualties	GSW n=68 Rate per 100 paediatric GSW casualties	CI difference in proportion	z-value and p-value
Debridement	63.4	50·0	−0.73−0.47	z=2·058; p=0·040 p<0·05
Laparotomy	24·0	35·3	−0.63−0.37	z=−1·971; p=0.054
Chest drain	12·3	2·9	−0.10−0.03	z=2·283; p=0.0230 p<0·05
Vascular procedures	11·7	10·3	−0.25−0.05	z=0·330; p=0.741
Temporary skeletal stabilisation	11·4	2·9	−0.10−0.03	z=2·131; p=0.034 p<0·05
Removal of fragmentation or ballistic materials	7·7	20·6	−0.45−0.20	z=−3·234; p=0.001 p<0·01
Fasciotomy	6·5	2·9	−0.11−0.01	z=1·148; p=0.252
Amputation	4·6	1·5	−0.09 -0.02	z=1·177; p=0.240
Thoracotomy	3·9	4·4	−0.16−0.01	z=−0·192; p=0.848
Sternotomy	1·2	1·5	−0.10−0.00	z=−0·202; p=0.840
Airway procedures	0·3	0	*	z=0.452; p=0.651
Flaps/skin graft/reconstruction	0·8	0	*	z=0·740; p=0.460
Burns	0	0	NA	NA

***Table 4b*: Standardised Surgical response to adult vs. paediatric ballistic casualties.**
Rate of surgical procedures per 100 adult ballistic casualties compared to paediatric ballistic casualties. Civilian casualties underwent immediate surgery for ballistic injuries (n=393) (Figures 2 and 3).

The five paediatric surgical interventions most commonly performed for blast were, in decreasing order of frequency: debridement, amputation, laparotomy, removal of fragmentation or ballistic material, chest drain insertion (Figure 3) and for ballistics: debridement, laparotomy, removal of fragmentation or ballistic materials, vascular procedures, and thoracotomy procedures (Figure 3).

Surgical characteristics blast vs. ballistics

Tables 1b and 2b show the standardised surgical response to adult and paediatric trauma casualties shown as a rate per 100 civilian casualties that suffered blast and ballistic injuries. All these data were used to design a standardised injury template to anticipate the numbers of surgical procedures required to manage any given mass casualty blast or ballistic event.

Adult blast casualties were associated with significantly more amputations (28·2) and removal of fragmentation materials (17·6) but significantly fewer chest drain insertions (7·7) compared to ballistic injuries (Figure 2; Table 1b: 4·6, z=8·407; p=0·0000; z=4·007; p=0·00007; 12·3, z=−2·164; p=0·030).

In paediatric casualties, those with blast injuries underwent significantly more amputation procedures (27·9) compared to ballistic injuries (1.5) (Figure 3; Table 2b: z=4·497; p=0·00002).

Comparative analysis adults vs. paediatric casualties

Tables 3b and 4b respectively compare the surgical response between adults and paediatric casualties injured by blast (Figure 4; Table 3b) and ballistics (Figure 5; Table 4b).

Adults injured by blast underwent significantly more debridement (63·5); temporary skeletal stabilisation (13·2) and vascular procedures (12·8) compared to children (Figure 4; Table 3b: 43·4, z=4·026, p=0·00007; 5·7, z=2·230, p=0·022; 4·9, z=2·468, p=0·014).

Adults injured by ballistics significantly more underwent debridement (63·4); chest drain (12·3) and

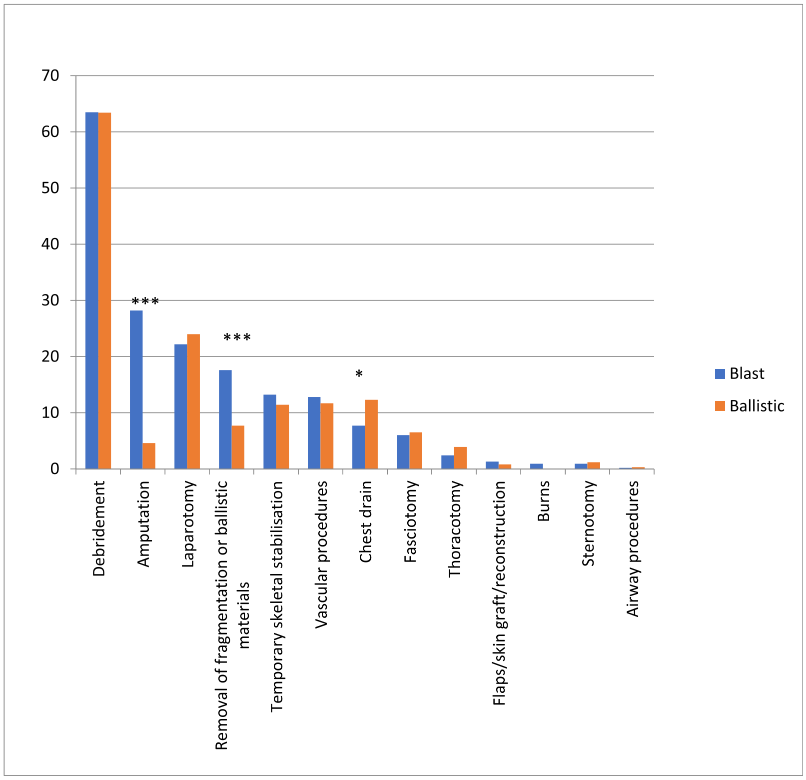

Figure 2. Surgical procedures on adult blast vs. ballistic casualties.

Surgical procedures most frequently performed on adult casualties injured by blast vs. ballistic (see Table 1b for data. No notation represents non-signifcance, notation *p<0.05; ** p<0.01, *** p<0.001 accordingly).

temporary skeletal fixation procedures (11·4) compared to children (Figure 5; Table 4b: 50·0, z=2·058, p=0.040; 2·9, z=2·283, p=0.023, p<0·05; 2·9, z=2·131, p=0.034 respectively).

Children injured by ballistics underwent significantly more removal of fragmentation or ballistic materials (20·6) when compared to adults (Figure 5; Table 4b: 7·692, z=−3·234, p=0.001).

Discussion

This study was designed to provide urgent and much needed evidence on the effect of blast and ballistic weapons on surgical procedures in civilian patients. Our data shows through analysis of 10,891 surgical cases, the largest surgical database caused by violence available in the world, for the first time the type of injuries sustained and the immediate surgical response required. The key findings are that the immediate surgical response is similar for adult versus paediatric populations and that though there are some variations in the surgical response between blast and ballistic injuries, the most common four surgical procedures for both mechanisms are the same. The primary aim of this study was to provide evidence to support clinicians to make decisions about the appropriate allocation of surgical resources for civilians injured in other armed conflicts e.g. Ukraine, as well as MCE, where applicable.

This study provides a baseline/starter dataset and if we collect more data from other scenarios then we can understand how the battle space environment e.g. weapons and geography influences the data. This study enables the best template of the most likely injuries civilians may suffer in war/terror-acts from blast and ballistic wounding mechanisms, and the most probable consequent surgical interventions. We caveat that with this having the greatest application to future conflicts which are predominantly rural, asymmetric, and fought with total air superiority, and with access to a well-established trauma facility within an hour or so of injury. We are collaborating with Ukrainian colleagues to see if an equivalent dataset can be generated there.

This study further characterizes the different injury patterns produced by blast and ballistic weapons.[10] It demonstrates the different effects of these wounding mechanisms on adult versus paediatric casualties. The results can be translated and used to standardise the type of surgical response needed and allow the development of more informed decision making when designing systems to respond to these types of casualties.

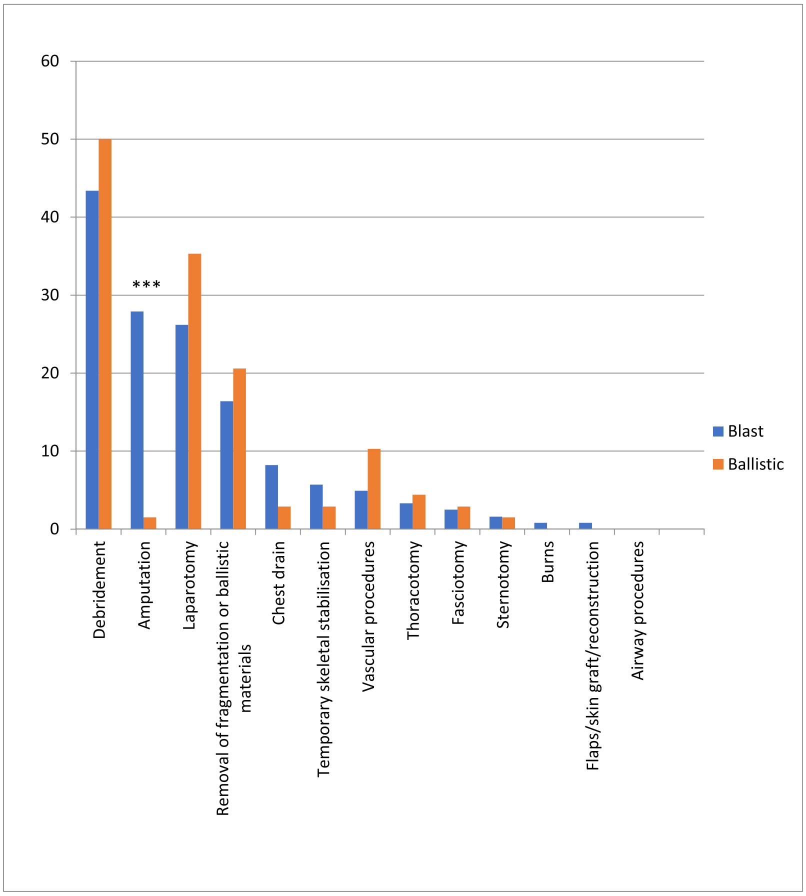

Figure 3. Surgical procedures on paediatric blast vs. ballistic casualties.
Surgical procedures most frequently performed on paediatric casualties injured by blast vs. ballistic (see Table 2b for data. No notation represents non-significance, notation *$p<0.05$; ** $p<0.01$, *** $p<0.001$ accordingly).

Wounding patterns show how head and abdominal region trauma predominates for both blast and ballistic injuries in children (Body Map Tables 1a–4a). Perhaps this relates to the disproportionately large head in relation to the rest of their body, and perhaps or over-cautious surgeries where abdomens were opened as a precaution.[14] Adult wounding patterns showed vulnerabilities of the extremities predominantly for blast and ballistic trauma (Tables 1a–4a).

These data confirm the well documented biomechanical differences between blast and ballistic injury, but the translation of this into what is required surgically to manage such injuries is less well described.[16,17] According to Table 1b, the main difference between the surgical management of blast and ballistic injuries in adults include significantly more amputations and removal of fragmentation materials compared to those injured by ballistics (Table 1b) and significantly more chest drain insertions to manage ballistic injuries compared to blast injuries (Table 1b). In paediatric casualties, there were more similarities in the surgical procedures required to manage blast and ballistic injuries with just significantly more amputations performed for blast injuries compared to ballistic (Table 2b); a finding which is consistent with Arul et al., (2012) who found that extremities were the most commonly affected paediatric region.[18] Their findings are similar to ours and practically, Tables 1b and 2b can be used to quantify the surgical response in future mass casualty blast or ballistic events, terror-related or otherwise.

In order to prepare the medical response to MCEs , our analysis highlights important differences in the surgical care provision for adult compared to paediatric casualties. Adults injured from blast undergo significantly more debridement; temporary skeletal stabilisation, and vascular procedures compared to paediatric casualties (Table 3b). Adult ballistic casualties undergo significantly more debridement, chest drain and temporary skeletal stablisation compared to children (Table 4b). Ballistic trauma in children lead to significantly more removal of ballistic materials compared to adults (Table 4b). Few reports on paediatric care in Afghanistan are available for comparison to the present study due to small cases numbers (for example Coppola et al, 2006, n=85; Arul et al, 2012, n=82).[18,19]

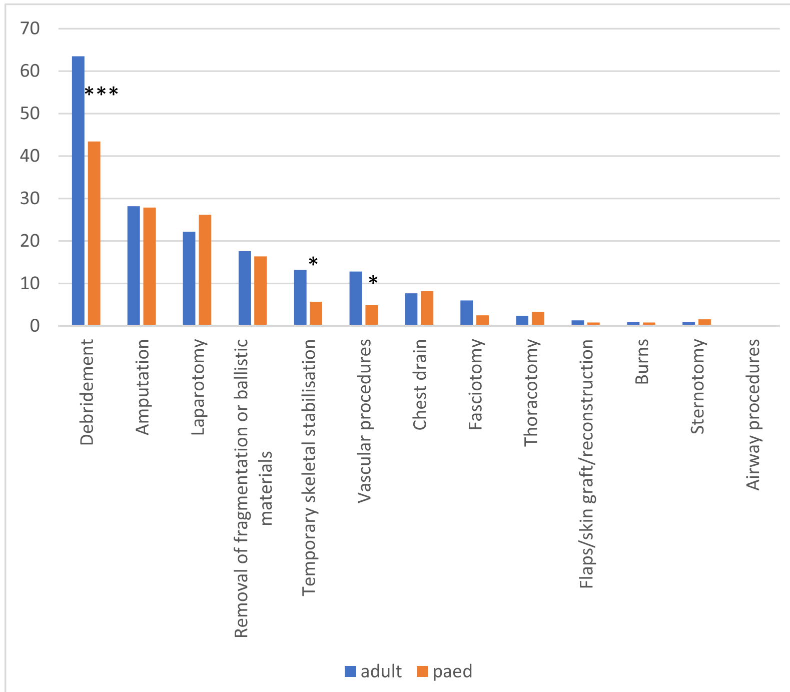

Figure 4. Surgical procedures on adult and paediatric blast casualties.

Surgical procedures most frequently performed on adult vs paediatric casualties injured by Blast (see Table 3b for data. No notation represents non-significance, notation *p<0.05; ** p<0.01, *** p<0.001 accordingly).

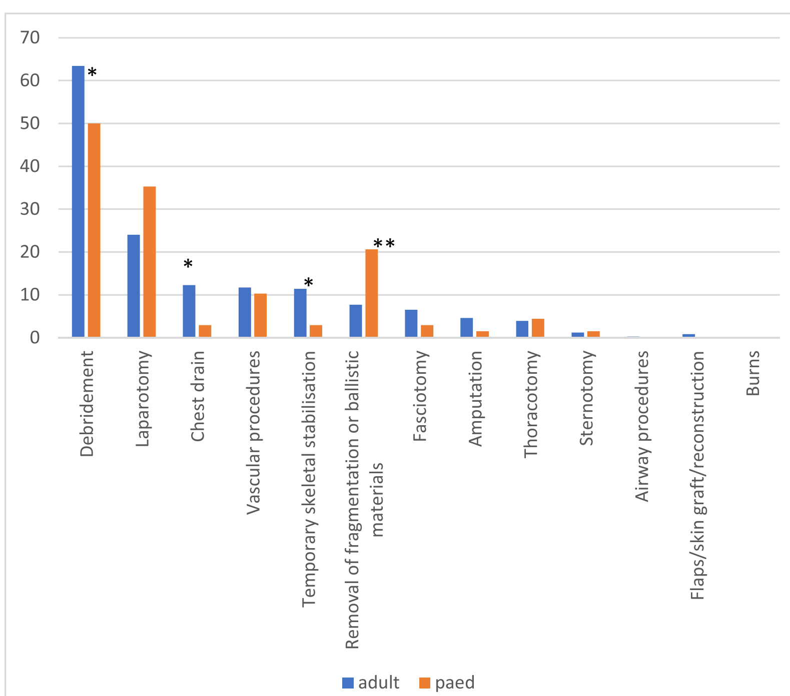

Figure 5. Surgical procedures on adult and paediatric ballistic casualties.

Surgical procedures most frequently performed on civilian adult vs paediatric casualties injured by Ballistics (see Table 4b for data. No notation represents non-significance, notation *p<0.05; ** p<0.01, *** p<0.001 accordingly).

Debridement and washout procedures remained the most common surgical procedure in paediatric casualties (Figures 2 and 3).[4,20,21] The present study enables us to understand the surgical burden for blast and ballistic wounding mechanisms in paediatric casualties.

Compared to larger studies on the paediatric cohort, we show that 19% (*n*=511) of operations were carried out on paediatric casualties. This compared to 14.7% (*n*=245) reported by Ramasamy and colleagues and 5.1% (*n*=85; *n*=99) reported in Iraq [Coppola et al., 2006 and McGuigan 2006] and 6% (*n*=299) reported by Jacobs et al., (2012).[5,6,19,22] Some larger studies like Borgman (2012) (*n*=7505) found that paediatric trauma accounted for 5.8% of admissions, however, this study and other larger comparable studies report data from Iraq and Afghanistan and data from hospital teams that were placed close to the point of injury with limited resources and so their results cannot be translated to resource rich setting e.g. Creamer 2009, (*n*=2060) and Edwards et al, (2014) (*n*=982).[20,23,24] Although these studies have large admission numbers, it is not clear how many of those required primary damage control surgery, nor the procedures they required.

The effect of the cultural and or religious unacceptability of serious physical injury like amputation requires additional considerations on surgical care provision for civilians (present study; Coupland 1991).[25] There were clear gender differences in our findings. There were no female trauma casualties, and 12 female civilian casualties recorded in our dataset, all of which were not trauma related, but rather emergency surgeries such as appendectomy or caesarean section etc. (8 adult, 4 paediatric) (i.e. 0.004% of the dataset). Creamer and colleagues (2009) reported girls accounting for 21% of paediatric admissions, and a significantly higher mortality rate in girls.[24] This suggests a male dominance for trauma, and, also probable cultural issues whereby female trauma patients did not receive the same care as male patients, suggesting an inequality of access to trauma care for females within the native population.[26]

It is possible that inaccuracies might have occurred during data collection; however, records were prospectively recorded by surgical teams involved in the case and were experienced in collecting surgical data. It is likely more operations were civilian casualties but did not have civilian status recorded in the handwritten operative logbooks. Since all casualties operated on were included in the database, regardless of injury type, selection bias was minimised.

A further limitation of this study, is that civilians treated in military hospitals in Afghanistan experienced survival bias, since it was assumed the most severely injured died during transfer or did not make it to the hospital.[27–30] However, in the present study cohort, the civilians were brought by the same pre-hospital provision as military casualties, which were on an equal if not superior footing, to what is available outside of a conflict zone.

In light of the evidence, as blast injuries become more prevalent in peacetime, the surgical skills outlined in this study are sadly no longer confined to the military, or overseas armed conflicts.[7] With the increase in terror-related attacks in cities at home, there is a recognised need to improve readiness for terror attacks in addition to armed conflicts, in order to manage the major trauma, which inevitably occurs.[1,7,30]

Since the end of combat operations in Afghanistan (2014), the rise in terror attacks has presented a unique challenge for the doctors and surgeons practicing in our local cities.[1] Major trauma training is, however, not prioritised in the UK despite four separate terror attacks having occurred in 2017 alone: Westminster Bridge (22 March); Manchester Arena bombing (22 May), the London Bridge attack (3 June) Parsons Green underground station (15 Sept).[1,7] These events involved mass casualties that resulted in 37 deaths and more than 265 people injured.[30] The need for trauma training remains an issue for all medical professionals.[7] Whilst the surgical procedures to manage these events remain uncommon day to day in the civilian world, it could be concluded that the training needs are also highlighted from the present study. The template presented helps to highlight raw numbers and provision at the system level (to allocate resources, theatres and staff and movement of casualties), but also brings focus to any training needs this may show for the individual surgeon and wider team.

This study was designed to assess the effect of blast and ballistic wounding patterns on surgical procedures in civilian casualties, thereby creating a template of immediate treatment, needs to help countries to enable Emergency Preparedness, Resilience and Response (EPRR) planning. Overall these findings support the use of this template for planning for armed conflicts and mass casualty events, which, given the likely continuance of terror attacks, has been recognised by NHS England as important.[1] The findings show the importance of a standardised surgical template, based on evidence, to optimise the immediate medical response and improve patient outcomes. This is particularly important since there is a magic number for the management of blast casualties, with surgeons with >50 blast surgical cases having a reduced case fatality rate (manuscript in preparation).[14]

A comprehensive evidence-based surgical requirement for the management of blast and ballistic wounds has yet to be defined, and there remains no current international agreement.[2] This study aims to support policy makers in making informed decisions about precisely what the medical needs are by providing stratified frequency tables to enable decision-makers to better determine the type and scale of the immediate surgical response required in armed conflicts, or in the immediate aftermath of a MCE, in order to deliver the right surgical procedures to save lives.

Contributors

LM designed the study, carried out the data collection, database creation, data analysis and interpretation as well as writing of the manuscript. SH conceived the analytical design, and with LM wrote the first draft of the manuscript. L.Middleton and LM carried out the statistical analysis. SH and DH verified the underlying data. All authors were involved in each stage of the planning, interpretation of the results and write up of the work. All authors approved the final version, had access to the data, contributed to writing and editing the manuscript and accept responsibility to submit the final version for publication.

Data sharing statement

All data sharing and collaboration requests should be directed to the corresponding author.

Declaration of interests

We declare no competing interests. L.Middleton is an employee of AstraZenica.

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