Future 'unexpected' survivors – fatal injuries from IED blast trauma 2007-2010: retrospective cohort study

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The BMJ Open editorial team

Dear Sir/Madam,

<u>RE: Future ‘unexpected’ survivors – fatal injuries from IED blast trauma 2007-2010: retrospective cohort study</u>

I wish to submit the above manuscript for consideration for publication in ‘BMJ Open’.

This study reports on the causes of death in combat casualties following improvised explosive device (IED) strikes, and areas in which research should focus to further improve outcomes, specifically acute survival, after these events.

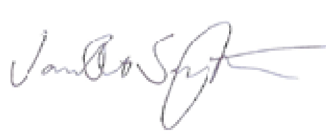
Due to recent conflicts in Iraq and Afghanistan, IEDs have achieved global notoriety as a cause of death and injury. These devices injure more soldiers and civilians currently than any other explosive mechanism, including landmines. With the recent adoption of postmortem CT imaging for military fatalities, performed within hours of death, a new opportunity has arisen to study IED blast trauma in greater detail than ever.

I would argue that it is imperative that we both learn and disseminate any lessons learnt from those military personnel who have made the ultimate sacrifice, in order to contribute to minimising future injuries from IED strikes. Publication through BMJ Open would allow this important message to reach the wide readership that I believe it deserves and would be of interest to.

The unfortunate reality is that IED strikes are not limited to Middle Eastern battlefields. Excluding Afghanistan and Iraq (>1000 IED incidents per month), there are still an estimated 500 IED strikes worldwide every month. This is clearly a global issue, affecting both civilians and military personnel, and therefore, studies in this area have wide, international and trans-specialty relevance in keeping with your publication and your readership.

Many thanks for your time and consideration. I look forward to hearing from you.

Yours sincerely,



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Future 'unexpected' survivors – fatal injuries from IED blast trauma 2007-2010: retrospective cohort study

ABSTRACT

Objectives: To identify fatal injury patterns in explosive blast fatalities in order to focus research and mitigation strategies, to further improve survival rates from blast trauma.

Design: Retrospective cohort study.

Participants: UK military personnel killed by IED blasts in Afghanistan, November 2007 – August 2010.

Setting: UK military deployment, through NATO, in support of the International Security Assistance Force (ISAF) mission in Afghanistan.

Data sources: UK military postmortem CT records, UK Joint Theatre Trauma Registry and associated incident data.

Main outcome measures: Fatal injuries attributable to IEDs.

Results: We identified 121 cases, 42 mounted (in-vehicle) and 79 dismounted (on foot) at point of wounding. There were 354 potentially fatal injuries in total. Leading causes of death were traumatic brain injury (48.4%, 60/124 fatal injuries), followed by intra-cavity haemorrhage (21.7%, 27/124) in the mounted group, and extremity haemorrhage (42.6%, 98/230 fatal injuries), junctional haemorrhage (22.2%, 51/230 fatal injuries) and traumatic brain injury (18.7%, 43/230 fatal injuries) in the dismounted group.

Conclusions: Head trauma severity in both mounted and dismounted IED fatalities indicated prevention and mitigation as the most effective strategies to decrease resultant mortality. Two thirds of dismounted fatalities had haemorrhage implicated as a cause of death that may have been amenable to pre-hospital intervention. One fifth of mounted fatalities had haemorrhagic trauma which currently could only be addressed surgically. Maintaining the drive to improve all haemostatic techniques for blast casualties, from point of wounding to definitive surgical proximal vascular control, alongside development and application of novel haemostatic interventions could yield a significant survival benefit. Prospective studies in this field are indicated.

ARTICLE SUMMARY

Article focus

- We investigated the cause of death in modern battlefield fatalities following IED blasts with cohorts of both dismounted (on foot) and mounted (in-vehicle) troops, in order to direct future research and treatment directions.
- We hypothesised that patterns of cause of death could be identified that would inform mitigation and novel treatment development in both military and civilian domains.

Key messages

- We describe the fatal injury profile due to IEDs for both dismounted and mounted casualties for the first time.
- For dismounted IED fatalities, extremity and junctional (groin/axilla/neck) haemorrhage are significant, potentially treatable, causes of death.
- In-vehicle IED casualties most frequently die of head injuries too severe to be treatable. Efforts to reduce the impact of such injuries should be made through mitigating/preventative strategies.

Strengths and limitations of this study

This is the largest series of IED fatalities reported to date with comprehensive CT and autopsy records. Studies such as this are invariably retrospective due to the constraints of battlefield trauma research, but meaningful analysis can still be performed – indeed there is an imperative to analyse fatality data to minimise future potential loss of life. Clear injury trends are identified that can guide mortality and morbidity reduction strategies.

INTRODUCTION

Currently, the improvised explosive device (IED) is the most prevalent cause of fatal battlefield injury.[1] The US Department of Defense has defined IEDs as "devices placed or fabricated in an improvised manner incorporating destructive, lethal; noxious, pyrotechnic or incendiary chemicals, designed to destroy, disfigure, distract or harass and often incorporate military stores".[2] IEDs have been shown to generate a different injury profile compared to conventional munitions, and blast injuries secondary to IEDs are also relatively less well characterised.[3] It is important to note that IED strikes are not limited to Middle Eastern warzones. For 2012, excluding Iraq or Afghanistan, more than 500 IED strikes occurred per month worldwide (mean monthly rates in Afghanistan for 2011-2012 were over 1300).[4] Victims may be in vehicles (mounted), or in the open (dismounted). Therefore, advances in both mitigating and treating the effects of IEDs could benefit not just military medicine and force protection but also civilian medical practice and counter-IED technologies.

Combat casualty care has undergone significant advances in recent years. Progress has been made in multiple areas, including improved personal protective equipment for troops, innovations in pre-hospital care, expedited casualty evacuation and new in-hospital damage control resuscitation protocols optimised for battlefield trauma cases. Consequently, coalition forces are currently achieving the highest recorded survival rates from battlefield injury - greater than 90% in Afghanistan compared to 85% in Vietnam and 80% in World War II.[5] These modern survival rate statistics include cases with such severe injuries that until recently they would have been considered *unexpected survivors.*[6] Sadly, certain injuries remain fatal. However, while some trauma may always be genuinely unsurvivable, other injuries, currently untreatable, may yet be amenable to intervention in the future. To identify these potential 'future unexpected survivors', an urgent requirement exists to analyse IED blast fatality data. Characterisation of resultant injury patterns can contribute to informing prevention, mitigation and clinical strategies and research activity. This can then bring about further improvements in combat casualty care and civilian trauma management.

All UK military combat fatalities undergo formal autopsy by a forensic pathologist following repatriation to the UK. Furthermore, in November 2007, full body post mortem CT (PM-CT) imaging was adopted by the UK military. PM-CT scans are performed at the deployed field hospitals - previously in Iraq and currently in Afghanistan - as soon as feasible after death. Use of forensic CT imaging was first reported in 1977 as an adjunct to traditional physical post-mortem examination[7], yet has risen to prominence as a frequently used forensic investigation in only the last 10-15 years.[8 9] Some have even suggested cross- sectional imaging techniques – combined CT and MRI – have the potential to replace traditional autopsy.[10] This remains a controversial subject and this study is neither advocating nor opposing this view. There can be little doubt, however, that PM-CT is of considerable value to forensic pathologists in circumstances involving trauma, especially skeletal injury, and foreign material detection[11 12], both of which are highly relevant in combat casualties. Therefore, with autopsy and PM-CT imaging, multimodal tools now exist with which to document and learn from fatal battlefield injury with access to high levels of anatomical detail never previously available.

We investigated the cause of death in modern battlefield fatalities following IED blasts with cohorts of both dismounted and mounted troops, in order to direct future research and treatment directions. We hypothesised that patterns of cause of death could be identified that would inform mitigation and novel treatment development in both military and civilian domains.

METHODS

Custodianship of the PM-CT images rests with Her Majesty's Coroners. Therefore we obtained permission to access the PM-CT dataset prior to commencing the study. Permission was also granted by Home Office accredited forensic pathologists to analyse relevant autopsy data and the study was approved by UK Joint Medical Command.

Inclusion criteria were: any UK military IED fatality – both *died of wounds* (DOW) (i.e. died following arrival at a medical facility) and *killed in action* (KIA) (i.e. certified dead prior to arrival at a medical facility) cases - with available PM-CT imaging and available UK Joint Theatre Trauma Registry (JTTR) data occurring within the study period. The UK JTTR is a prospectively collected trauma database of every UK military casualty admitted to a medical facility or killed on deployed operations. In the case of fatalities, a military research nurse attends the formal autopsy performed once the body has been repatriated to the UK. The pathologist's findings are then entered into the JTTR. Retrospective analysis was undertaken of all UK military personnel killed by IED blasts with available PM-CT imaging and relevant incident data from November 2007 - inception of PM-CT imaging – to August 2010 The UK JTTR was interrogated for injury data, relevant incident data, and casualty location at point of wounding (in-vehicle/mounted or on foot/dismounted). Intervals between time of wounding, time of death and time of PM-CT scan were recorded. All PM-CT scans were reported by a single military consultant (IG) the UK's most experienced radiologist in this area.

A cause of death analysis was performed. An anatomical trauma severity classification system was required and the *Abbreviated Injury Scale (AIS) 2005-Military Edition* was appropriate.[13] This system identifies nine body regions (head, face, neck, thorax, abdomen, spine, upper extremities, lower extremities and external) and uses an anatomic ordinal scale to score trauma severity, from one (minor injury) to six (maximum injury, currently unsurvivable). The Injury Severity Score (ISS) evolved from the AIS and comprises an ordinal score from 1 to 75.[14] The nine regions were grouped into six (head/neck, face, chest, abdomen (including pelvic contents), extremities (including pelvic girdle) and external). The score consists of the sum of the squares of the three highest scoring regions. If an injury to any region scores six, the ISS is automatically 75. The literature suggests that the ISS under-represents multiple injuries from the same anatomical region and so the New Injury Severity Score (NISS) was introduced[15], in which the score is the sum of the squares of the three highest scoring injuries regardless of region. Modern battlefield blast fatalities have been shown to sustain injuries to multiple AIS regions.[16] This contrasts with previous data from World War II, and the Korean and Vietnam Wars, where the majority of combat fatalities were observed to have sustained only one life threatening 'hit'.[17] It has been argued that it is not possible to accurately determine the relative lethality of multiple potentially lethal injuries[18], and that in the context of battlefield trauma, injuries with an AIS≥4 have significant lethal potential.[13] We took these factors into account in devising our cause of death analysis methodology. Thus, equal weighting was given to all three injuries contributing to the NISS and we excluded any injuries with AIS≤3. This generated overall totals of lethal injuries by AIS region. NISS was more appropriate than ISS given the frequency of multiple injuries to a single region in blast trauma, and because NISS has been shown to be a better predictor of mortality than ISS.[15]

We then assessed mechanism of death for every fatal injury (AIS≥4). We classified haemorrhagic injuries as extremity – amenable to tourniquet control- , junctional – potentially amenable to compression –, or intra-cavity – requiring surgical haemostasis. It was necessary to amalgamate anatomically separate groups into unifying mechanistic groups. This helped to clarify intra-group trends and facilitate inter-group comparison; we combined groin, neck and axillary haemorrhagic injuries to form an overall junctional haemorrhage group. Upper and lower limb haemorrhagic injuries constituted the extremity haemorrhage group. Intra-cranial, Intra-thoracic and intra-abdominal bleeds made up the intra-cavity haemorrhage group. Head and spinal neurological injuries contributed to the CNS injury group.

We performed statistical analysis using SPSS version 20.0 (IBM, Armonk, NY). For initial cohort comparison, we used the Mann-Whitney *U* (MWU) test to compare ages of the mounted (M) and dismounted (DM) groups - these variables were not normally distributed (testing for normality using the Shapiro-Wilk test generated a *p*-value of 0.023 for the M group and 0.001 for the DM group). We also compared time intervals, number of AIS regions sustaining lethal injury and total number of AIS regions injured per casualty using a Mann-Whitney *U* test, as these data sets were also non-parametric with Shapiro-Wilk *p*-values < 0.05. We used Fisher's exact test for inter-group comparison of specific causes of death. A *p*-value < 0.05 was considered significant.

RESULTS

Study group composition

212 PM-CT fatality investigations were performed during the study period. This translated to a study group of 121 of which 42/121 were mounted (M) at time of wounding and 79/121 were in a dismounted (DM) environment when wounded (Figure 1).

Figure 1 - study group composition.

Initial cohort comparison

We found no significant differences between ages of the mounted and dismounted cohorts. 120 of 121 cases were male. The median interval from injury to scan for all 121 cases was 313 minutes (IQR 224-780), comprising median intervals of 81 minutes between injury and death, and 232 minutes from death to CT scan (further details in Table 1). The age profiles, wounding-death-scan intervals and number of AIS regions with lethal injuries did not differ significantly between groups (Table 1). 62% (26/42) of mounted fatalities and 56% (44/79) of dismounted fatalities had potentially fatal injuries to two or more anatomical regions (≥2 AIS regions contributing to the NISS score).

Table 1. Cohort comparison: Mounted vs. Dismounted

Group variable		Mounted (n=42)	Dismounted (n=79)	Overall (n=121)	M vs DM, *p* value
Age in yrs		25.5, (22-30)[ϟ]	25.0, (21-29)[ϟ]	25 (21-29)[ϟ]	0.345
ToW* - ToD† in mins		78, (36-113)[ϟ]	85, (58-196)[ϟ]	81 (50-145)[ϟ]	0.110
ToD – ToS‡ in mins		246, (160-714)[ϟ]	216, (89-900)[ϟ]	232 (105-712)[ϟ]	0.234
Number of AIS regions with fatal injuries (%)	**1**	16 (38)	35 (44)	51	0.492
	2	22 (52)	38 (48)	60	
	≥3	4 (10)	6 (8)	10	

*time of wounding, †time of death, ‡time of scan, [ϟ]median (interquartile range)

Severity and anatomical burden of injury

Mounted fatalities had significantly higher NISS (p=0.012, MWU) values compared to dismounted fatalities indicating greater injury burden (Figure 2).

Figure 2 – NISS scores for mounted and dismounted fatalities

Mounted fatalities suffered injuries to significantly more AIS regions than dismounted fatalities with median values of 6 and 4 regions injured respectively. (p<0.0001 MWU; Figure 3).

Figure 3 – AIS regions injured per fatality, mounted vs. dismounted

Cause and mechanism of death in blast fatalities

Clear differences were also evident in the anatomical distribution of fatal injuries in dismounted and mounted groups as shown in Table 2. Of note, 9/363 injuries making up the NISS scores were less than four, and were excluded from further analysis ,leaving 354 fatal injuries in total.

Table 2. Fatal injury rates by AIS region: Mounted (M) vs. Dismounted (DM)

AIS region	% of fatal injuries within group		M vs DM CoD rates, *p* value (Fishers)
	M (n=124)	DM (n=230)	
Head	53% (66)	19% (43)	<0.0001
Thorax	23% (29)	8% (18)	<0.0001
Lower extremity	7% (9)	48% (111)	<0.0001
Abdomen	8% (10)	13% (31)	0.1636
Neck	2% (2)	3% (8)	0.5039
Spine	4% (5)	3% (7)	0.7594
Other trauma	2% (2)	1% (3)	1.0000
Upper extremity	1% (1)	3% (7)	0.2695
Face	0% (0)	1% (2)	0.5435

Mechanism of death from these injuries was calculated, as previously described. The resultant chart is shown in Figure 4.

Figure 4 – Mechanism of death, mounted vs. dismounted

DISCUSSION

Fatal injury distribution and effect of environment on extent of injuries

Mounted and dismounted blast casualties presented here demonstrate significantly different fatal injury profiles with respect to incidence of head, lower extremity and thoracic injuries (p<0.0001). Resultant mechanism of death also varied according to location at point of wounding. For mounted IED fatalities, CNS trauma, (most commonly severe traumatic brain injury (TBI) rather than spinal cord trauma) was the leading mechanism of death, followed by intra cavity haemorrhage. In dismounted IED fatalities haemorrhage predominated, most commonly from extremity bleeding, followed by junctional blood loss.

This study also demonstrates that blast fatalities in vehicles are both more severely and more widely injured than dismounted blast fatalities. One might expect the vehicle to mitigate both the occupant's surface area affected by injurious components of the blast and the severity of injury sustained, but these hypotheses are not supported by our data. Clearly, type and size of IED will have a bearing on injury severity and distribution.[3 16] However, the sensitive nature of such munition data is self-evident and so any future work utilising such incident data would have to satisfy the understandable security issues.

Strengths and weaknesses

This is the largest series of IED fatalities reported to date with comprehensive CT and autopsy records. Studies such as this are invariably retrospective due to the constraints of battlefield trauma research, but meaningful analysis can still be performed – indeed there is an imperative to analyse fatality data to minimise future potential loss of life.

This study was based on injury data from the UK JTTR rather than solely PM-CT findings. All injuries noted at autopsy are stored in the UK JTTR. Furthermore, PM-CT results were available to the investigating pathologist; therefore the autopsy report can be considered a synergistic product of the radiological and physical investigations. Standard (i.e. non-contrast) PM-CT has inherent limitations - essentially decreased sensitivity for vascular and hollow visceral injuries compared to formal autopsy.[19] PM-CT angiography can redress this, but is an evolving science and is both time- and labour intensive compared to a standard CT scan, requiring invasive access to the femoral vessels, non-standard contrast media and a heart-lung bypass machine to temporarily restore circulation.[20] This would not be appropriate considering the clinical work load at the military hospital at Camp Bastion, Afghanistan where the PM-CTs are performed.

A potential weakness of PM-CT for trauma fatalities is loss of diagnostic sensitivity secondary to artefact either from resuscitation and/or decomposition. However, the autopsy was performed with the knowledge of any resuscitative procedures performed. Also, the median intervals between time of wounding and time of death were less than 90 minutes and those between time of death and time of scan were less than four hours,(and in cases with any significant delay to scan, the deceased were transferred to refrigerated mortuary conditions). Therefore, neither prior interventions nor decomposition artefact would have been likely to cause diagnostic issues in this study.

Comparisons with other studies

Such a comparison, as performed in our study, has not been presented previously for modern combat blast fatalities. To date, cause of death analyses for mounted and/or dismounted blast fatalities have tended to be reported with mounted fatalities as a separate group[16], as an amalgamated group[18], or amalgamated and in conjunction with other injury mechanisms such as gunshot wounds (GSWs), aircraft crashes and motor vehicle collisions (MVCs).[21]

Nelson *et al* reported a case series of 18 US military IED casualties injured in Iraq in 2004, of whom nine died.[22] Injuries were described in individual narratives, and were recorded clinically. No postmortem examination/imaging was reported. Of note, one of three mounted fatalities and four of six dismounted fatalities sustained severe head injuries. Our series also contained multiple cases of fatal head trauma, indicating this to be a consistent injury pattern amongst IED fatalities.

Farkash *et al* reported a case series of 22 Israeli Defence Force combat fatalities undergoing PM-CT from September 1997 and December 1998 following explosive trauma.[8] Formal autopsy is frequently opposed in Israel on religious grounds and only four cases underwent physical autopsy. Furthermore, extremities were not CT scanned in the Israeli group (head, neck, chest, abdomen, and pelvis only) and no summary injury severity data were presented. PMCT demonstrated injuries to the head/neck in 86% (19), Face 50% (11), Chest 77% (17), Abdomen 32% (7) and Extremities 36% (8). Without injury severity data, little further can be derived from this.

Eastridge *et al* looked at cause of death in 558 died of wounds (DOW) US combat fatalities from Iraq and Afghanistan from October 2001 until June 2009, thus including both conventional warfighting and counter insurgency phases of combat.[23] Data sources included peri-mortem medical records, autopsy reports and photos. PM-CT was not listed as a data source. Consistent with our methodology, when multiple wounds per casualty were noted, each wound was evaluated individually. There was no differentiation between mounted and dismounted fatalities and killed in action (KIA) cases were excluded, although of note, 232 cases were admitted to medical facilities in extremis with CPR in progress. Cases were classified as 'non-survivable' (NS, 271/558) or 'potentially survivable' (PS, 287/558), nomenclature in keeping with previous US-led cause of death analyses.[21] Again, explosions were the main cause of injury (72%) followed by GSWs (25%), MVCs (2%) and helicopter crashes (1%). TBI was a cause of death in 83% of NS and 9% of PS cases, whilst haemorrhage was the causal mechanism in 16% of NS and 80% of PS cases. This concurs with our conclusions regarding research strategies most likely to decrease mortality from head trauma/TBI – prevention-orientated – and haemorrhage – improved haemostatic techniques at all levels of care. The exclusion of KIA cases prevents further meaningful comparison with this study but serves to highlight an inherent difficulty with combat casualty data analysis – truly differentiating between KIA and DOW cases, when multiple cases have arrived at medical facilities with ongoing CPR, is a complex task. We elected to analyse both KIA and DOW cases in order to capture the full spectrum of acutely fatal blast injuries.

Studies by Bellamy in 1984 [17] and more recently by Champion et al in 2003 [24] presented summary data of all combat injuries sustained by US Marine and Army personnel in jungle combat in Vietnam from 1967-1969 based on clinical records and autopsy data. This database of 7,989 patients contains both survivors and fatalities and mounted and dismounted casualties. The majority were blast injuries (62% fragment, 3% (primary) blast) with 23% GSWs, 6% burns and 6% other mechanisms Champion showed a distribution of site of lethal injury as follows: 37% head, 24% chest, 9% abdomen, 3% extremity.. Interestingly while this is initially similar to modern mounted blast fatalities (52% head, 25% chest, 8% abdomen, 8% extremity), Champion noted only 17% with multiple lethal injuries. Furthermore, Bellamy, analysing the same data, observed autopsy findings of multiple potentially fatal wounds in only 30 of 500 cases (6%). This contrasts markedly with our study group, in which 70/121 (58%) of cases sustained 2 or more potentially fatal injuries. In spite of the Vietnam data including GSW fatalities – more likely than blast casualties to sustain a single lethal injury - , the increased incidence of multiple lethal injuries per fatality in the modern data is likely to represent a real difference. This may reflect differing weapons systems responsible for the blast injuries, with greater relative use of conventional ordinance in Vietnam - artillery shells, mortars, grenades etc. – compared to IEDs, the sole injury mechanism in our series.

Such simultaneous commonality and difference emphasises the point that, in battlefield trauma analysis, comparisons between casualties from different theatres of war and certainly from different eras must be made with caution, as many factors including weapons systems, tactics, casualty evacuation and medical capabilities must be considered.

Future unexpected survivors

Blast CNS trauma tended to be of a severe blunt traumatic brain injury pattern and beyond redress with current medical management. Determining precise aetiology in mounted fatalities is complex, given victim exposure to multiple modalities with injurious potential. These include primary blast – the shockwave - , and tertiary blast at multiple instances as a vehicle is first accelerated upwards by the blast wind and then undergoes rapid deceleration on landing. Efforts to reduce mortality and morbidity from these devastating head injuries are likely to be most efficacious if concentrated on prevention and mitigation strategies, such as crew restraint and protection and improved helmet design against blunt trauma, rather than treatment after the blast.

Death in dismounted troops was most commonly due to haemorrhage, mainly from extremity, then junctional trauma. Our data suggest there is potential to decrease mortality thorough appropriately targeted haemostatic interventions such as compression *when possible* for these extremity and junctional injuries. There is good evidence that recent (2006 onwards), widespread adoption of pre-hospital tourniquet use for severe extremity haemorrhage from combat wounds has saved lives.[25] Despite this, civilian medical organisations appear to remain reluctant to add pre-hospital tourniquets to their armamentarium. While indications for tourniquet use may be fewer in civilian trauma, the fact that they have been shown to improve survival following battlefield trauma highlights their potential to do the same in civilian trauma, in appropriate circumstances. It should also be noted that haemorrhage control continues to evolve. A US Food and Drug Administration approved junctional tourniquet, the Combat Ready Clamp (Combat Medical Systems, Fayetteville, NC) is currently being introduced in Afghanistan and truncal tourniquets have been stated as a US Department of Defense research priority.[26] The effective employment of such devices, if able to achieve pre-hospital haemostasis for blast casualties and others with haemorrhagic junctional trauma, clearly has the potential to improve survival rates.

In contrast, the majority of mounted deaths from haemorrhage were due to intra-cavity haemorrhage, likely to have required surgical intervention too early (immediately or within minutes) to be feasible to provide in a contemporary combat environment. Recent operations in Afghanistan have shown casualty evacuation times from point of wounding to hospital of 75 minutes,[27] and this may be an emerging trend in more asymmetric conflicts. However, in more traditional scenarios such as the first Gulf War of 1991, the mean time taken from injury to arriving at a British surgical hospital was 10.2 hours and by the second Gulf War of 2003, with much shorter lines of communication and better casualty evacuation, the mean delay was still six hours.[28] This contrasts markedly with reports from the civilian environment. A study by Demetriades *et al* in 1996 of 5782 patients in California showed a mean interval of just 37 minutes from 911 call notification of emergency medical personnel to arrival at a trauma centre.[29] Therefore, even interventions with a brief or transient therapeutic window may be of benefit in improving the chances of getting a blast trauma patient with non-compressible bleeding to the surgical team alive. These may include pre-hospital adoption of haemostatic resuscitation techniques and use of novel pharmacological agents to prevent/reverse coagulopathy and certainly merit further study.[30] This applies both to the military setting, where several such techniques are already employed or under review, and to civilian trauma, with potential applicability beyond blast trauma.

CONCLUSIONS

IEDs are currently the main cause of death for deployed coalition troops and are likely to remain so for the foreseeable future. Worldwide, IED strikes are also common against civilians. In mounted fatalities following IED strikes, severe head injury was the main cause of death. Given the devastating nature of the associated traumatic brain injury, prevention and mitigation, rather than advances in medical treatment, are the most likely strategies to decrease mortality. Fatal haemorrhage in mounted casualties was most commonly intra-thoracic or intra-abdominal, currently only treatable surgically, with no effective pre-hospital intervention available.

This study has also shown that nearly two thirds of dismounted IED fatalities died from exsanguinating extremity or junctional haemorrhage, with lower limb the most common site. Maintaining the drive to improve all haemostatic techniques, from point of wounding to definitive surgical proximal control, alongside development and application of novel haemostatic devices and pharmacological agents could yield a significant survival benefit. This work and such techniques have relevance beyond military medicine to the many civilian trauma services that currently treat IED victims or may have to manage such cases in the future.

CONFLICTS OF INTEREST STATEMENT

All authors have completed the Unified Competing Interest form at www.icmje.org/coi_disclosure.pdf (available on request from the corresponding author) and declare

that JS, IG, NH, AB and JC have no relationships with companies that might have an interest in the submitted work in the previous 3 years; their spouses, partners, or children have no financial relationships that may be relevant to the submitted work; and JS, IG, NH, AB and JC have no non-financial interests that may be relevant to the submitted work.

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All authors had full access to the all of the data, and can take responsibility for the integrity of the data and the accuracy of the data analysis.

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Data sharing:

Given the sensitive anture of the data and security implications, no additional data is available.

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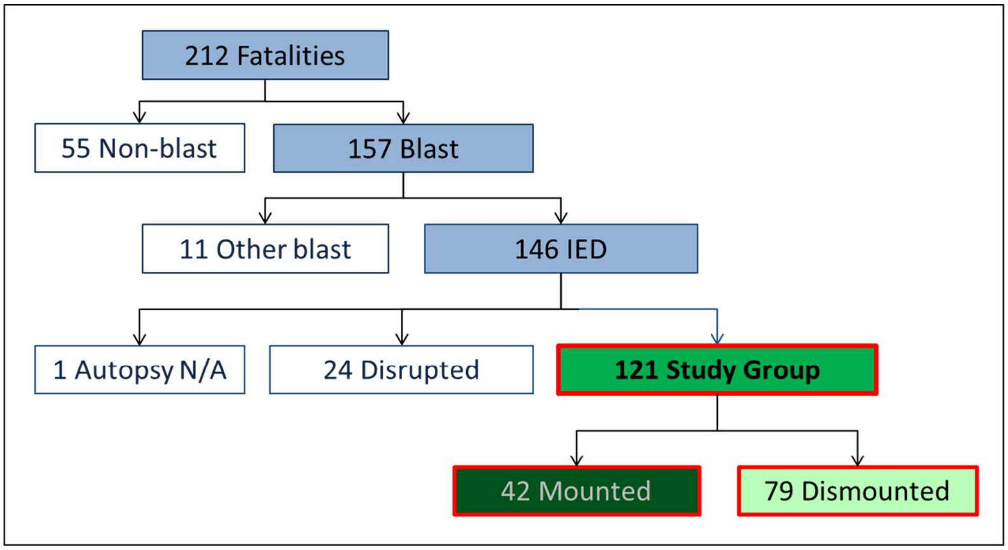

Figure 1 - study group composition
214x116mm (300 x 300 DPI)

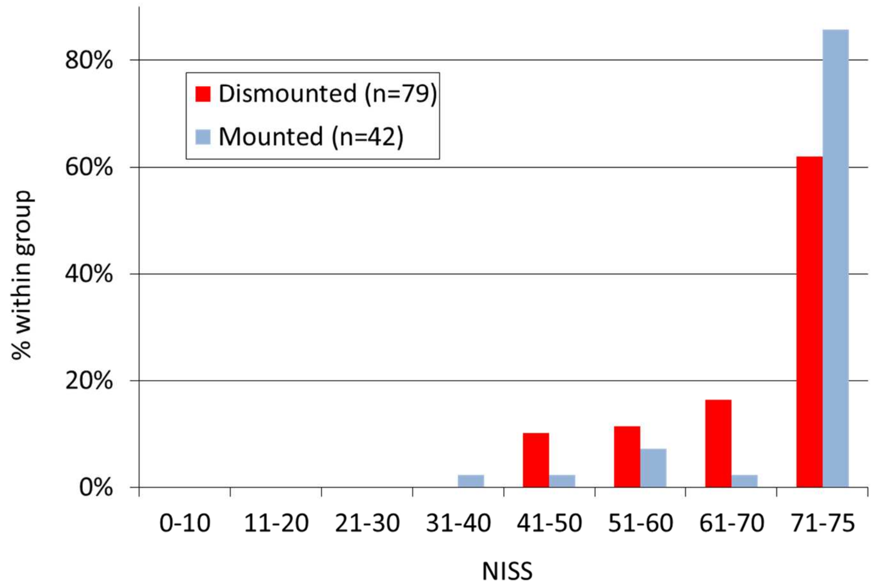

Figure 2 – NISS scores for mounted and dismounted fatalities
226x142mm (300 x 300 DPI)

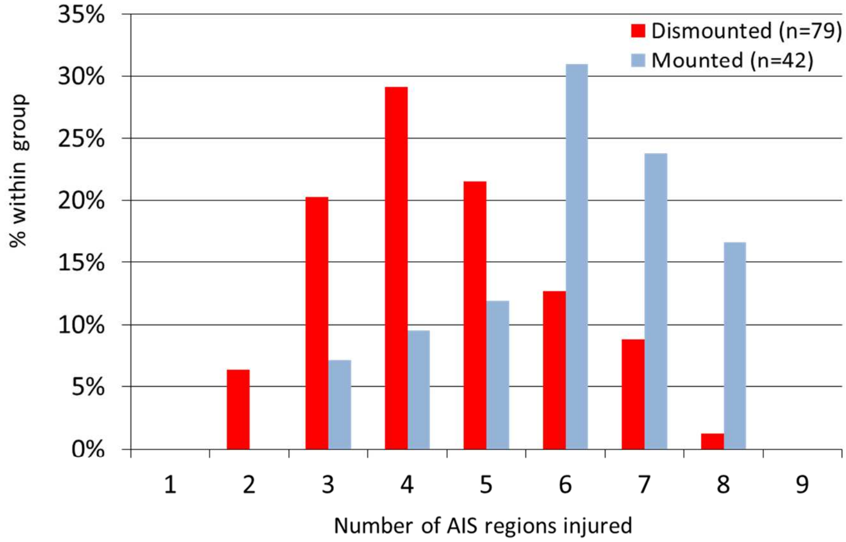

Figure 3 – AIS regions injured per fatality, mounted vs. dismounted
230x136mm (300 x 300 DPI)

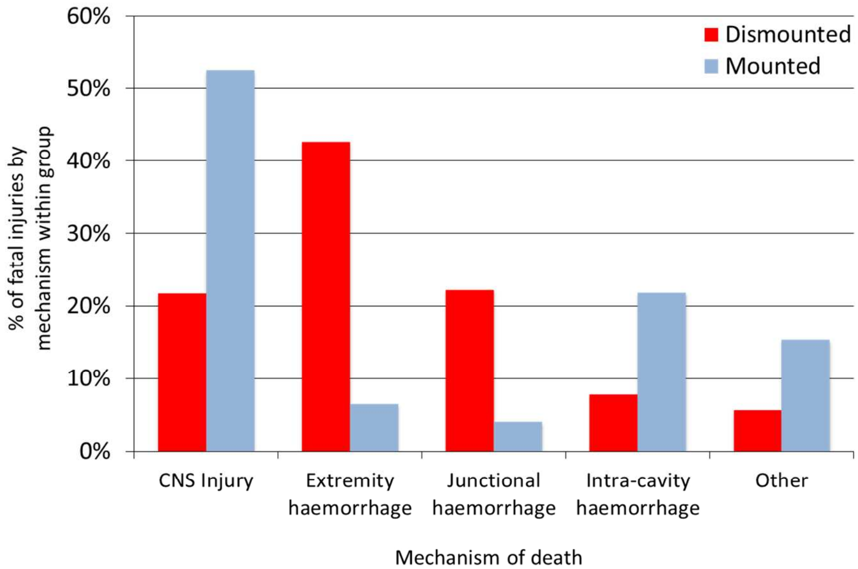

Figure 4 – Mechanism of death, mounted vs. dismounted
249x159mm (300 x 300 DPI)

Future 'unexpected' survivors – fatal injuries from IED blast trauma 2007-2010: retrospective cohort study

James A G Singleton, Iain E Gibb, Nicholas A C Hunt, Anthony M J Bull, Jon C Clasper

STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***

	Item No	Recommendation	Addressed
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	Y
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	Y
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	Y
Objectives	3	State specific objectives, including any prespecified hypotheses	Y
Methods			
Study design	4	Present key elements of study design early in the paper	Y
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Y
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up	Y
		(*b*) For matched studies, give matching criteria and number of exposed and unexposed	N/A
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	Y
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	Y
Bias	9	Describe any efforts to address potential sources of bias	Y
Study size	10	Explain how the study size was arrived at	Y
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	Y
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	Y
		(*b*) Describe any methods used to examine subgroups and interactions	Y
		(*c*) Explain how missing data were addressed	N/A
		(*d*) If applicable, explain how loss to follow-up was addressed	N/A
		(*e*) Describe any sensitivity analyses	N/A
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	Y
		(b) Give reasons for non-participation at each stage	Y
		(c) Consider use of a flow diagram	Y
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic,	Y

		clinical, social) and information on exposures and potential confounders	
		(b) Indicate number of participants with missing data for each variable of interest	Y
		(c) Summarise follow-up time (eg, average and total amount)	N/A
Outcome data	15*	Report numbers of outcome events or summary measures over time	Y
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	Y
		(*b*) Report category boundaries when continuous variables were categorized	Y
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	N/A
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	Y
Discussion			
Key results	18	Summarise key results with reference to study objectives	Y
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	Y
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	Y
Generalisability	21	Discuss the generalisability (external validity) of the study results	Y
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	Y

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.

Identifying future ‘unexpected’ survivors: a retrospective cohort study of fatal injury patterns in victims of improvised explosive devices

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Identifying future 'unexpected' survivors: a retrospective cohort study of fatal injury patterns in victims of improvised explosive devices

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Keywords: Cause of Death , Battlefield Trauma , IED

Number of Words: 4387

ABSTRACT

Objectives: To identify potentially fatal injury patterns in explosive blast fatalities in order to focus research and mitigation strategies, to further improve survival rates from blast trauma.

Design: Retrospective cohort study.

Participants: UK military personnel killed by IED blasts in Afghanistan, November 2007 – August 2010.

Setting: UK military deployment, through NATO, in support of the International Security Assistance Force (ISAF) mission in Afghanistan.

Data sources: UK military postmortem CT records, UK Joint Theatre Trauma Registry and associated incident data.

Main outcome measures: Potentially fatal injuries attributable to IEDs.

Results: We identified 121 cases, 42 mounted (in-vehicle) and 79 dismounted (on foot) at point of wounding. There were 354 potentially fatal injuries in total. Leading causes of death were traumatic brain injury (50%, 62/124 fatal injuries), followed by intra-cavity haemorrhage (20.2%, 25/124) in the mounted group, and extremity haemorrhage (42.6%, 98/230 fatal injuries), junctional haemorrhage (22.2%, 51/230 fatal injuries) and traumatic brain injury (18.7%, 43/230 fatal injuries) in the dismounted group.

Conclusions: Head trauma severity in both mounted and dismounted IED fatalities indicated prevention and mitigation as the most effective strategies to decrease resultant mortality. Two thirds of dismounted fatalities had haemorrhage implicated as a cause of death that may have been amenable to pre-hospital intervention. One fifth of mounted fatalities had haemorrhagic trauma which currently could only be addressed surgically. Maintaining the drive to improve all haemostatic techniques for blast casualties, from point of wounding to definitive surgical proximal vascular control, alongside development and application of novel haemostatic interventions could yield a significant survival benefit. Prospective studies in this field are indicated.

ARTICLE SUMMARY

Article focus

- We investigated the cause of death in modern battlefield fatalities following IED blasts with cohorts of both dismounted (on foot) and mounted (in-vehicle) troops, in order to direct future research and treatment directions.
- We hypothesised that patterns of cause of death could be identified that would inform mitigation and novel treatment development in both military and civilian domains.

Key messages

- We describe the potentially fatal injury profile due to IEDs for both dismounted and mounted casualties for the first time.

- For dismounted IED fatalities, extremity and junctional (groin/axilla/neck) haemorrhage are significant, potentially treatable, causes of death.
- In-vehicle IED casualties most frequently die of head injuries too severe to be treatable. Efforts to reduce the impact of such injuries should be made through mitigating/preventative strategies.

Strengths and limitations of this study

This is the largest series of IED fatalities reported to date with comprehensive CT and autopsy records. Studies such as this are invariably retrospective due to the constraints of battlefield trauma research, but meaningful analysis can still be performed – indeed there is an imperative to analyse fatality data to minimise future potential loss of life.

INTRODUCTION

Currently, the improvised explosive device (IED) is the most prevalent cause of fatal battlefield injury.[1] The US Department of Defense has defined IEDs as "devices placed or fabricated in an improvised manner incorporating destructive, lethal, noxious, pyrotechnic or incendiary chemicals, designed to destroy, disfigure, distract or harass and often incorporating military stores".[2] IEDs have been shown to generate a different injury profile compared to conventional munitions, and blast injuries secondary to IEDs are also relatively less well characterised.[3] It is important to note that IED strikes are not limited to Middle Eastern warzones. For 2012, excluding Iraq or Afghanistan, more than 500 IED strikes occurred per month worldwide (mean monthly rates in Afghanistan for 2011-2012 were over 1300).[4] Victims may be in vehicles (mounted), or in the open (dismounted). Therefore, advances in both mitigating and treating the effects of IEDs could benefit not just military medicine and force protection but also civilian medical practice and counter-IED technologies.

Combat casualty care has undergone significant advances in recent years. Progress has been made in multiple areas, including improved personal protective equipment for troops, innovations in pre-hospital care, expedited casualty evacuation and new in-hospital damage control resuscitation protocols optimised for battlefield trauma cases. Consequently, coalition forces are currently achieving the highest recorded survival rates from battlefield injury - greater than 90% in Afghanistan compared to 85% in Vietnam and 80% in World War II.[5] These modern survival rate statistics include cases with such severe injuries that until recently they would have been considered *unexpected survivors.*[6] Sadly, certain injuries remain fatal. However, while some trauma may always be genuinely unsurvivable, other injuries, currently untreatable, may yet be amenable to intervention in the future. To identify these potential 'future unexpected survivors', an urgent requirement exists to analyse IED blast fatality data. Characterisation of resultant injury patterns can contribute to informing prevention, mitigation and clinical strategies and research activity. This can then bring about further improvements in blast casualty care, both military and civilian.

All UK military combat fatalities undergo formal autopsy by a forensic pathologist following repatriation to the UK. Furthermore, in November 2007, full body post mortem CT (PM-CT) imaging was adopted by the UK military. PM-CT scans are performed at the deployed field hospitals - previously in Iraq and currently in Afghanistan - as soon as feasible after death. Use of forensic CT imaging was first reported in 1977 as an adjunct to traditional physical post-mortem examination[7], yet has risen to prominence as a frequently used forensic investigation in only the last 10-15 years.[8 9] Some have even suggested cross- sectional imaging techniques – combined CT and MRI – have the potential to replace traditional autopsy.[10] This remains a controversial subject and this study is neither advocating nor opposing this view. There can be little doubt, however, that PM-CT is of considerable value to forensic pathologists in circumstances involving trauma, especially skeletal injury, and foreign material detection[11 12], both of which are highly relevant in combat casualties. Therefore, with autopsy and PM-CT imaging, multimodal tools now exist with which to document and learn from fatal battlefield injury with access to high levels of anatomical detail never previously available.

We investigated the cause of death in modern battlefield fatalities following IED blasts with cohorts of both dismounted and mounted troops, in order to direct future research and treatment directions. We hypothesised that patterns of cause of death could be identified that would inform mitigation and novel treatment development in both military and civilian domains.

METHODS

Custodianship of the PM-CT images rests with Her Majesty's Coroners. Therefore we obtained permission to access the PM-CT dataset prior to commencing the study. Permission was also granted by Home Office accredited forensic pathologists to analyse relevant autopsy data and the study was approved by UK Joint Medical Command.

Inclusion criteria were: any UK military IED fatality – both *died of wounds* (DOW) (i.e. died following arrival at a medical facility) and *killed in action* (KIA) (i.e. certified dead prior to arrival at a medical facility) cases - with available PM-CT imaging and available UK Joint Theatre Trauma Registry (JTTR) data occurring within the study period. The UK JTTR is a prospectively collected trauma database of every UK military casualty admitted to a medical facility or killed on deployed operations, and includes details of any surgery prior to death. In the case of fatalities, a military research nurse attends the formal autopsy performed once the body has been repatriated to the UK. The pathologist's findings are coded using *Abbreviated Injury Scale (AIS) 2005-Military[13],* then entered into the JTTR. Retrospective analysis was undertaken of all UK military personnel killed by IED blasts with available PM-CT imaging and relevant incident data from November 2007 - inception of PM-CT imaging – to August 2010 The UK JTTR was interrogated for injury data, relevant incident data, and casualty location at point of wounding (in-vehicle/mounted or on foot/dismounted). Intervals between time of wounding, time of death and time of PM-CT scan were recorded. Further detail concerning vehicle type or injury specifics beyond that presented here could not be published due to over-riding security/vulnerability issues. All PM-CT scans were reported by a single military consultant (IG) the UK's most experienced radiologist in reporting post mortem blast trauma imaging.

A cause of death analysis was performed. An anatomical trauma severity classification system was required and the *AIS 2005-Military Edition* was appropriate. This system identifies nine body regions (head, face, neck, thorax, abdomen, spine, upper extremities, lower extremities and external) and uses an anatomic ordinal scale to score trauma severity, from one (minor injury) to six (maximum injury, currently unsurvivable). The Injury Severity Score (ISS) evolved from the AIS and comprises an ordinal score from 1 to 75. The nine regions were grouped into six (head/neck, face, chest, abdomen (including pelvic contents), extremities (including pelvic girdle) and external). The score consists of the sum of the squares of the three highest scoring regions. If an injury to any region scores six, the ISS is automatically 75. The literature suggests that the ISS under-represents multiple injuries from the same anatomical region and so the New Injury Severity Score (NISS) was introduced[14], in which the score is the sum of the squares of the three highest scoring injuries regardless of region. Modern battlefield blast fatalities have been shown to sustain injuries to multiple AIS regions.[15] This contrasts with previous data from World War II, and the Korean and Vietnam Wars, where the majority of combat fatalities were observed to have sustained only one life threatening 'hit'.[16] It has been argued that it is not possible to accurately determine the relative lethality of multiple potentially fatal injuries[17], and that in the context of battlefield trauma, injuries with an AIS≥4 have significant lethal potential.[13] We took these factors into account in devising our cause of death analysis methodology. Thus, equal weighting was given to all three injuries contributing to the NISS and we excluded any injuries with AIS≤3. This generated overall totals of potentially fatal injuries by AIS region. NISS was more appropriate than ISS given the frequency of multiple injuries to a single region in blast trauma, and because NISS has been shown to be a better predictor of mortality than ISS.[14]

We then assessed mechanism of death for every fatal injury (AIS≥4). We classified haemorrhagic injuries as extremity – amenable to tourniquet control- , junctional – potentially amenable to compression –, or intra-cavity – requiring surgical haemostasis. It was necessary to amalgamate anatomically separate groups into unifying mechanistic groups. This helped to clarify intra-group trends and facilitate inter-group comparison; we combined groin, neck and axillary haemorrhagic injuries to form an overall junctional haemorrhage group. Upper and lower limb haemorrhagic injuries constituted the extremity haemorrhage group. Intra-cranial, Intra-thoracic and intra-abdominal bleeds made up the intra-cavity haemorrhage group. Of note, only a single open head injury contributed to this group. Head and spinal neurological injuries, including contained intra-cranial bleeds, contributed to the CNS injury group.

We performed statistical analysis using SPSS version 20.0 (IBM, Armonk, NY). For initial cohort comparison, we used the Mann-Whitney *U* (MWU) test to compare ages of the mounted (M) and dismounted (DM) groups - these variables were not normally distributed (testing for normality using the Shapiro-Wilk test generated a p-value of 0.023 for the M group and 0.001 for the DM group). We also compared time intervals, number of AIS regions sustaining lethal injury and total number of AIS regions injured per casualty using a Mann-Whitney *U* test, as these data sets were also non-parametric with Shapiro-Wilk p-values < 0.05. We used Fisher's exact test for inter-group comparison of specific causes of death and mechanism of death. A p-value < 0.05 was considered significant.

RESULTS

Study group composition

212 PM-CT fatality investigations were performed during the study period. This translated to a study group of 121 of which 42/121 were mounted (M) at time of wounding and 79/121 were in a dismounted (DM) environment when wounded (Figure 1).

Figure 1 - study group composition.

Initial cohort comparison

We found no significant differences between ages of the mounted and dismounted cohorts. 120 of 121 cases were male. The median interval from injury to scan for all 121 cases was 313 minutes (IQR 224-780), comprising median intervals of 81 minutes between injury and death, and 232 minutes from death to CT scan (further details in Table 1). The age profiles, wounding-death-scan intervals, KIA:DOW ratio and number of AIS regions with lethal injuries did not differ significantly between groups (Table 1). 62% (26/42) of mounted fatalities and 56% (44/79) of dismounted fatalities had potentially fatal injuries to two or more anatomical regions (≥2 AIS regions contributing to the NISS score).

Table 1. Cohort comparison: Mounted vs. Dismounted

Group variable		Mounted (n=42)	Dismounted (n=79)	Overall (n=121)	M vs DM, *p* value
Age in yrs		25.5, (22-30)[ϟ]	25.0, (21-29)[ϟ]	25 (21-29)[ϟ]	0.345
ToW* - ToD† in mins		78, (36-113)[ϟ]	85, (58-196)[ϟ]	81 (50-145)[ϟ]	0.110
ToD – ToS‡ in mins		246, (160-714)[ϟ]	216, (89-900)[ϟ]	232 (105-712)[ϟ]	0.234
KIA (%)		38 (90)	70 (89)	108	1.000
DOW (%)		4 (10)	9 (11)	13	1.000
Number of AIS regions with fatal injuries (%)	1	16 (38)	35 (44)	51	0.492
	2	22 (52)	38 (48)	60	
	≥3	4 (10)	6 (8)	10	

*time of wounding, †time of death, ‡time of scan, [ϟ]median (interquartile range)

Severity and anatomical burden of injury

Mounted fatalities had significantly higher NISS (p=0.012, MWU) values compared to dismounted fatalities indicating greater injury burden (Figure 2).

Figure 2 – NISS scores for mounted and dismounted fatalities

Mounted fatalities suffered injuries to significantly more AIS regions than dismounted fatalities with median values of 6 and 4 regions injured, respectively. (p<0.0001 MWU; Figure 3).

Figure 3 – AIS regions injured per fatality, mounted vs. dismounted

Cause and mechanism of death in blast fatalities

Clear differences were also evident in the anatomical distribution of fatal injuries in dismounted and mounted groups as shown in Table 2. Of note, 9/363 injuries making up the NISS scores were less than four, and were excluded from further analysis ,leaving 354 fatal injuries in total.

Table 2. Fatal injury rates by AIS region: Mounted (M) vs. Dismounted (DM)

AIS region	% of fatal injuries within group		M vs DM CoD rates, *p* value (Fishers)
	M (n=124)	DM (n=230)	
Head	53% (66)	19% (43)	<0.0001
Thorax	23% (29)	8% (18)	<0.0001
Lower extremity	7% (9)	48% (111)	<0.0001
Abdomen	8% (10)	13% (31)	0.1636
Neck	2% (2)	3% (8)	0.5039
Spine	4% (5)	3% (7)	0.7594
Other trauma	2% (2)	1% (3)	1.0000
Upper extremity	1% (1)	3% (7)	0.2695
Face	0% (0)	1% (2)	0.5435

Mechanism of death from these injuries was calculated, as previously described. The resultant chart is shown in Figure 4.

Figure 4 – Mechanism of death, mounted vs. dismounted

DISCUSSION

Fatal injury distribution and effect of environment on extent of injuries

Mounted and dismounted blast casualties presented here demonstrate significantly different potentially fatal injury profiles with respect to incidence of head, lower extremity and thoracic injuries (p<0.0001). Resultant mechanism of death also varied according to location at point of wounding. For mounted IED fatalities, CNS trauma, (most commonly severe traumatic brain injury (TBI) rather than spinal cord trauma) was the leading mechanism of death, followed by intra cavity haemorrhage. In dismounted IED fatalities haemorrhage predominated, most commonly from extremity bleeding, followed by junctional blood loss.

This study also demonstrates that blast fatalities in vehicles are both more severely and more widely injured than dismounted blast fatalities. One might expect the vehicle to mitigate both the occupant's surface area affected by injurious components of the blast and the severity of injury sustained, but these hypotheses are not supported by our data. Clearly, type and size of IED will have a bearing on injury severity and distribution.[3 15] However, the sensitive nature of such munition data is self-evident and so any future work utilising such incident data would have to satisfy the understandable security issues.

Strengths and weaknesses

This is the largest series of IED fatalities reported to date with comprehensive CT and autopsy records. Studies such as this are invariably retrospective due to the constraints of battlefield trauma research, but meaningful analysis can still be performed – indeed there is an imperative to analyse fatality data to minimise future potential loss of life.

This study was based on injury data from the UK JTTR rather than solely PM-CT findings. All injuries noted at autopsy are stored in the UK JTTR. Furthermore, PM-CT results were available to the investigating pathologist; therefore the autopsy report can be considered a synergistic product of the radiological and physical investigations. Standard (i.e. non-contrast) PM-CT has inherent limitations - essentially decreased sensitivity for vascular and hollow visceral injuries compared to formal autopsy.[18] PM-CT angiography can redress this, but is an evolving science and is both time- and labour intensive compared to a standard CT scan, requiring invasive access to the femoral vessels, non-standard contrast media and a heart-lung bypass machine to temporarily restore circulation.[19] This would not be appropriate considering the clinical work load at the military hospital at Camp Bastion, Afghanistan where the PM-CTs are performed.

A potential weakness of PM-CT for trauma fatalities is loss of diagnostic sensitivity secondary to artefact either from resuscitation and/or decomposition. However, the autopsy was performed with the knowledge of any resuscitative procedures performed. Also, the median intervals between time of wounding and time of death were less than 90 minutes and those between time of death and time of scan were less than four hours,(and in cases with any significant delay to scan, the deceased were transferred to refrigerated mortuary conditions). Therefore, neither prior interventions nor decomposition artefact would have been likely to cause diagnostic issues in this study.

Comparisons with other studies

Such a comparison, as performed in our study, has not been presented previously for modern combat blast fatalities. To date, cause of death analyses for mounted and/or dismounted blast fatalities have tended to be reported with mounted fatalities as a separate group[15], as an amalgamated group[17], or amalgamated and in conjunction with other injury mechanisms such as gunshot wounds (GSWs), aircraft crashes and motor vehicle collisions (MVCs).[20]

Nelson *et al* reported a case series of 18 US military IED casualties injured in Iraq in 2004, of whom nine died.[21] Injuries were described in individual narratives, and were recorded clinically. No postmortem examination/imaging was reported. Of note, one of three mounted fatalities and four of six dismounted fatalities sustained severe head injuries. Our series also contained multiple cases of fatal head trauma, indicating this to be a consistent injury pattern amongst IED fatalities.

Farkash *et al* reported a case series of 22 Israeli Defence Force combat fatalities undergoing PM-CT from September 1997 and December 1998 following explosive trauma.[8] Formal autopsy is frequently opposed in Israel on religious grounds and only four cases underwent physical autopsy. Furthermore, extremities were not CT scanned in the Israeli group (head, neck, chest, abdomen, and pelvis only) and no summary injury severity data were presented. PMCT demonstrated injuries to the head/neck in 86% (19), face 50% (11), chest 77% (17), abdomen 32% (7) and extremities 36% (8). Without injury severity data, little further can be derived from this.

In 2011, Eastridge *et al* published their findings on cause of death in 558 died of wounds (DOW) US combat fatalities from Iraq and Afghanistan from October 2001 until June 2009, thus including both conventional warfighting and counter insurgency phases of combat.[22] Eastridge *et al* followed this up in 2012 with an analysis of 4596 US combat fatalities, of which 4016 were killed in action (KIA), again from Iraq and Afghanistan, from October 2001 until June 2011.[23] Data sources included peri-mortem medical records, autopsy reports and photos. PM-CT was not listed as a data source. Consistent with our methodology, when multiple wounds per casualty were noted, each wound was evaluated individually. There was no differentiation between mounted and dismounted fatalities in either study. Of note in the DOW cohort, 232/558 cases were admitted to medical facilities in extremis with CPR in progress. Cases were classified as ‘non-survivable’ (NS, 271/558 DOW, 3040/4016 KIA) or ‘potentially survivable’ (PS, 287/558 DOW, 976/4016 KIA), nomenclature in keeping with previous US-led cause of death analyses.[20] Again, explosions were the main cause of injury (DOW 72%, KIA 74%) followed by GSWs (DOW 25%, KIA 22%), then other causes (DOW, MVCs 2%, helicopter crashes 1%, KIA 'other' (e.g. MVC, crush) 4%). Both DOW and KIA groups showed TBI to be the predominant cause of death in their NS groups (83% and 45% respectively) and haemorrhage as the main causal mechanism in their PS groups (80% and 91% respectively). This concurs with our conclusions regarding research strategies most likely to decrease mortality from head trauma/TBI – prevention-orientated – and haemorrhage – improved haemostatic techniques at all levels of care. Subgroup data of lethal haemorrhage cases was only presented for PS cases but merits comparison with our study. We demonstrate a higher proportion of extremity haemorrhage cases as a proportion of all haemorrhage cases – 52% - then either the PS DOW group – 31% - or the PS KIA group – 13% - , similar rates of junctional haemorrhage – 27% in our study vs. 21% PS DOW and 19 % PS KIA – and a corresponding lower rate of intra-cavity haemorrhage – 21% vs. 48% PS DOW and 67% PS KIA). This may be explained in part by the presence of GSW cases in the DOW and KIA groups and the likely penetrating thoracoabdominal wounding pattern of significant numbers of these cases.

Studies by Bellamy in 1984 [16] and more recently by Champion et al in 2003 [24] presented summary data of all combat injuries sustained by US Marine and Army personnel in jungle combat in Vietnam from 1967-1969 based on clinical records and autopsy data. This database of 7,989 patients contains both survivors and fatalities and mounted and dismounted casualties. The majority were blast injuries (62% fragment, 3% (primary) blast) with 23% GSWs, 6% burns and 6% other mechanisms Champion showed a distribution of site of lethal injury as follows: 37% head, 24% chest, 9% abdomen, 3% extremity. Interestingly, while this is initially similar to modern mounted blast fatalities (52% head, 25% chest, 8% abdomen, 8% extremity), Champion noted only 17% with multiple lethal injuries. Furthermore, Bellamy, analysing the same data, observed autopsy findings of multiple potentially fatal wounds in only 30 of 500 cases (6%). This contrasts markedly with our study group, in which 70/121 (58%) of cases sustained 2 or more potentially fatal injuries. In spite of the Vietnam data including GSW fatalities – more likely than blast casualties to sustain a single lethal injury - , the increased incidence of multiple lethal injuries per fatality in the modern data is likely to represent a real difference. This may reflect differing weapons systems responsible for the blast injuries, with greater relative use of conventional ordinance in Vietnam - artillery shells, mortars, grenades etc. – compared to IEDs, the sole injury mechanism in our series.

Such simultaneous commonality and difference emphasises the point that, in battlefield trauma analysis, comparisons between casualties from different theatres of war and certainly from different eras must be made with caution, as many factors including weapons systems, tactics, casualty evacuation and medical capabilities must be considered.

Future unexpected survivors

Blast CNS trauma tended to be of a severe blunt traumatic brain injury pattern and beyond redress with current medical management. Determining precise aetiology in mounted fatalities is complex, given victim exposure to multiple modalities with injurious potential. These include primary blast – the shockwave - , and tertiary blast at multiple instances as a vehicle is first accelerated upwards by the blast wind and then undergoes rapid deceleration on landing. Efforts to reduce mortality and morbidity from these devastating head injuries are likely to be most efficacious if concentrated on prevention and mitigation strategies, such as crew restraint and protection and improved helmet design against blunt trauma, rather than treatment after the blast.

Death in dismounted troops was most commonly due to haemorrhage, mainly from extremity, then junctional trauma. Our data suggest there is potential to decrease mortality thorough appropriately targeted haemostatic interventions such as compression *when possible* for these extremity and junctional injuries. There is good evidence that recent (2006 onwards), widespread adoption of pre-hospital tourniquet use for severe extremity haemorrhage from combat wounds has saved lives.[25] Civilian medical organisations have traditionally been reluctant to add pre-hospital tourniquets to their armamentarium.[26] While indications for tourniquet use may be fewer in civilian trauma, the fact that they have been shown to improve survival following battlefield trauma highlights their potential to do the same in civilian trauma, in appropriate circumstances, and this appears to have been demonstrated by the emergency medical services' response following the Boston Marathon bombing.[23] It should also be noted that haemorrhage control continues to evolve. A US Food and Drug Administration approved junctional tourniquet, the Combat Ready Clamp (Combat Medical Systems, Fayetteville, NC) is currently being introduced in Afghanistan and truncal tourniquets have been stated as a US Department of Defense research priority.[27] The effective employment of such devices, if able to achieve pre-hospital haemostasis for blast casualties and others with haemorrhagic junctional trauma, clearly has the potential to improve survival rates.

In contrast, the majority of mounted deaths from haemorrhage were due to intra-cavity haemorrhage, likely to have required surgical intervention too early (immediately or within minutes) to be feasible to provide in a contemporary combat environment. Recent operations in Afghanistan have shown casualty evacuation times from point of wounding to hospital of 75 minutes,[28] and this may be an emerging trend in more asymmetric conflicts. However, in more traditional scenarios such as the first Gulf War of 1991, the mean time taken from injury to arriving at a British surgical hospital was 10.2 hours and by the second Gulf War of 2003, with much shorter lines of communication and better casualty evacuation, the mean delay was still six hours.[29] This contrasts markedly with reports from the civilian environment. A study by Demetriades *et al* in 1996 of 5782 patients in California showed a mean interval of just 37 minutes from 911 call notification of emergency medical personnel to arrival at a trauma centre.[30] Therefore, even interventions with a brief or transient therapeutic window may be of benefit in improving the chances of getting a blast trauma patient with non-compressible bleeding to the surgical team alive. These may include pre-hospital adoption of haemostatic resuscitation techniques and use of novel pharmacological agents to prevent/reverse coagulopathy and certainly merit further study. This applies both to the military setting, where several such techniques are already employed or under review, and to civilian trauma, with potential applicability beyond blast trauma. However, the degree of benefit such techniques may confer to the general population, with a broader age range and greater pre-morbidity when compared to a military cohort, has yet to be determined.

CONCLUSIONS

IEDs are currently the main cause of death for deployed coalition troops and are likely to remain so for the foreseeable future. Worldwide, IED strikes are also common against civilians. In mounted fatalities following IED strikes, severe head injury was the main cause of death. Given the devastating nature of the associated traumatic brain injury, prevention and mitigation, rather than advances in medical treatment, are the most likely strategies to decrease mortality. Fatal haemorrhage in mounted casualties was most commonly intra-thoracic or intra-abdominal, currently only treatable surgically, with no effective pre-hospital intervention available.

This study has also shown that nearly two thirds of dismounted IED fatalities died from exsanguinating extremity or junctional haemorrhage, with lower limb the most common site. Maintaining the drive to improve all haemostatic techniques, from point of wounding to definitive surgical proximal control, alongside development and application of novel haemostatic devices and pharmacological agents could yield a significant survival benefit. This work and such techniques have relevance beyond military medicine to the many civilian trauma services that currently treat IED victims or may have to manage such cases in the future.

CONFLICTS OF INTEREST STATEMENT

All authors have completed the Unified Competing Interest form at www.icmje.org/coi_disclosure.pdf (available on request from the corresponding author) and declare that JS, IG, NH, AB and JC have no relationships with companies that might have an interest in the submitted work in the previous 3 years; their spouses, partners, or children have no financial relationships that may be relevant to the submitted work; and JS, IG, NH, AB and JC have no non-financial interests that may be relevant to the submitted work.

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DATA SHARING

No additional data available

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~~Future 'unexpected' survivors – fatal injuries from IED blast trauma 2007-2010: retrospective cohort study~~

Identifying future 'unexpected' survivors: a retrospective cohort study of fatal injury patterns in victims of improvised explosive devices

Comment [SJ1]: Title changed in response to NT's comments

ABSTRACT

Objectives: To identify potentially fatal injury patterns in explosive blast fatalities in order to focus research and mitigation strategies, to further improve survival rates from blast trauma.

Design: Retrospective cohort study.

Participants: UK military personnel killed by IED blasts in Afghanistan, November 2007 – August 2010.

Setting: UK military deployment, through NATO, in support of the International Security Assistance Force (ISAF) mission in Afghanistan.

Data sources: UK military postmortem CT records, UK Joint Theatre Trauma Registry and associated incident data.

Main outcome measures: Potentially fFatal injuries attributable to IEDs.

Results: We identified 121 cases, 42 mounted (in-vehicle) and 79 dismounted (on foot) at point of wounding. There were 354 potentially fatal injuries in total. Leading causes of death were traumatic brain injury (50%, 62/124 fatal injuries), followed by intra-cavity haemorrhage (20.2%, 25/124) in the mounted group, and extremity haemorrhage (42.6%, 98/230 fatal injuries), junctional haemorrhage (22.2%, 51/230 fatal injuries) and traumatic brain injury (18.7%, 43/230 fatal injuries) in the dismounted group.

Conclusions: Head trauma severity in both mounted and dismounted IED fatalities indicated prevention and mitigation as the most effective strategies to decrease resultant mortality. Two thirds of dismounted fatalities had haemorrhage implicated as a cause of death that may have been amenable to pre-hospital intervention. One fifth of mounted fatalities had haemorrhagic trauma which currently could only be addressed surgically. Maintaining the drive to improve all haemostatic techniques for blast casualties, from point of wounding to definitive surgical proximal vascular control, alongside development and application of novel haemostatic interventions could yield a significant survival benefit. Prospective studies in this field are indicated.

ARTICLE SUMMARY

Article focus

- We investigated the cause of death in modern battlefield fatalities following IED blasts with cohorts of both dismounted (on foot) and mounted (in-vehicle) troops, in order to direct future research and treatment directions.

- We hypothesised that patterns of cause of death could be identified that would inform mitigation and novel treatment development in both military and civilian domains.

Key messages

- We describe the potentially fatal injury profile due to IEDs for both dismounted and mounted casualties for the first time.
- For dismounted IED fatalities, extremity and junctional (groin/axilla/neck) haemorrhage are significant, potentially treatable, causes of death.
- In-vehicle IED casualties most frequently die of head injuries too severe to be treatable. Efforts to reduce the impact of such injuries should be made through mitigating/preventative strategies.

Strengths and limitations of this study

This is the largest series of IED fatalities reported to date with comprehensive CT and autopsy records. Studies such as this are invariably retrospective due to the constraints of battlefield trauma research, but meaningful analysis can still be performed – indeed there is an imperative to analyse fatality data to minimise future potential loss of life.

INTRODUCTION

Currently, the improvised explosive device (IED) is the most prevalent cause of fatal battlefield injury.[1] The US Department of Defense has defined IEDs as "devices placed or fabricated in an improvised manner incorporating destructive, lethal, noxious, pyrotechnic or incendiary chemicals, designed to destroy, disfigure, distract or harass and often incorporating military stores".[2] IEDs have been shown to generate a different injury profile compared to conventional munitions, and blast injuries secondary to IEDs are also relatively less well characterised.[3] It is important to note that IED strikes are not limited to Middle Eastern warzones. For 2012, excluding Iraq or Afghanistan, more than 500 IED strikes occurred per month worldwide (mean monthly rates in Afghanistan for 2011-2012 were over 1300).[4] Victims may be in vehicles (mounted), or in the open (dismounted). Therefore, advances in both mitigating and treating the effects of IEDs could benefit not just military medicine and force protection but also civilian medical practice and counter-IED technologies.

Combat casualty care has undergone significant advances in recent years. Progress has been made in multiple areas, including improved personal protective equipment for troops, innovations in pre-hospital care, expedited casualty evacuation and new in-hospital damage control resuscitation protocols optimised for battlefield trauma cases. Consequently, coalition forces are currently achieving the highest recorded survival rates from battlefield injury - greater than 90% in Afghanistan compared to 85% in Vietnam and 80% in World War II.[5] These modern survival rate statistics include cases with such severe injuries that until recently they would have been considered *unexpected survivors.*[6] Sadly, certain injuries remain fatal. However, while some trauma may always be genuinely unsurvivable, other injuries, currently untreatable, may yet be amenable to intervention in the future. To identify these potential 'future unexpected survivors', an urgent requirement exists to analyse IED blast fatality data. Characterisation of resultant injury patterns can contribute to informing prevention, mitigation and clinical strategies and research activity. This can then bring about further improvements in blast~~combat~~ casualty care~~ and civilian trauma management~~, both military and civilian.

All UK military combat fatalities undergo formal autopsy by a forensic pathologist following repatriation to the UK. Furthermore, in November 2007, full body post mortem CT (PM-CT) imaging was adopted by the UK military. PM-CT scans are performed at the deployed field hospitals - previously in Iraq and currently in Afghanistan - as soon as feasible after death. Use of forensic CT imaging was first reported in 1977 as an adjunct to traditional physical post-mortem examination[7], yet has risen to prominence as a frequently used forensic investigation in only the last 10-15 years.[8 9] Some have even suggested cross- sectional imaging techniques – combined CT and MRI – have the potential to replace traditional autopsy.[10] This remains a controversial subject and this study is neither advocating nor opposing this view. There can be little doubt, however, that PM-CT is of considerable value to forensic pathologists in circumstances involving trauma, especially skeletal injury, and foreign material detection[11 12], both of which are highly relevant in combat casualties. Therefore, with autopsy and PM-CT imaging, multimodal tools now exist with which to document and learn from fatal battlefield injury with access to high levels of anatomical detail never previously available.

We investigated the cause of death in modern battlefield fatalities following IED blasts with cohorts of both dismounted and mounted troops, in order to direct future research and treatment directions. We hypothesised that patterns of cause of death could be identified that would inform mitigation and novel treatment development in both military and civilian domains.

METHODS

Custodianship of the PM-CT images rests with Her Majesty's Coroners. Therefore we obtained permission to access the PM-CT dataset prior to commencing the study. Permission was also granted by Home Office accredited forensic pathologists to analyse relevant autopsy data and the study was approved by UK Joint Medical Command.

Inclusion criteria were: any UK military IED fatality – both *died of wounds* (DOW) (i.e. died following arrival at a medical facility) and *killed in action* (KIA) (i.e. certified dead prior to arrival at a medical facility) cases - with available PM-CT imaging and available UK Joint Theatre Trauma Registry (JTTR) data occurring within the study period. The UK JTTR is a prospectively collected trauma database of every UK military casualty admitted to a medical facility or killed on deployed operations, and includes details of any surgery prior to death. In the case of fatalities, a military research nurse attends the formal autopsy performed once the body has been repatriated to the UK. The pathologist's findings are coded using *Abbreviated Injury Scale (AIS) 2005-Military*[13], ~~are~~then entered into the JTTR. Retrospective analysis was undertaken of all UK military personnel killed by IED blasts with available PM-CT imaging and relevant incident data from November 2007 - inception of PM-CT imaging – to August 2010 The UK JTTR was interrogated for injury data, relevant incident data, and casualty location at point of wounding (in-vehicle/mounted or on foot/dismounted). Intervals between time of wounding, time of death and time of PM-CT scan were recorded. Further detail concerning vehicle type or injury specifics beyond that presented here could not be published due to over-riding security/vulnerability issues. All PM-CT scans were reported by a single military consultant (IG) the UK's most experienced radiologist in reporting post mortem blast trauma imaging~~this area~~.

A cause of death analysis was performed. An anatomical trauma severity classification system was required and the ~~*Abbreviated Injury Scale (*~~*AIS*~~*)*~~ *2005-Military Edition* was appropriate. This system identifies nine body regions (head, face, neck, thorax, abdomen, spine, upper extremities, lower extremities and external) and uses an anatomic ordinal scale to score trauma severity, from one (minor injury) to six (maximum injury, currently unsurvivable). The Injury Severity Score (ISS) evolved from the AIS and comprises an ordinal score from 1 to 75. The nine regions were grouped into six

Comment [JS2]: Added as per EE's comments

Comment [JS3]: To address both NT and EE's comments

Comment [JS4]: Changed as per NT's review (head/neck, face, chest, abdomen (including pelvic contents), extremities (including pelvic girdle) and external). The score consists of the sum of the squares of the three highest scoring regions. If an injury to any region scores six, the ISS is automatically 75. The literature suggests that the ISS under-represents multiple injuries from the same anatomical region and so the New Injury Severity Score (NISS) was introduced[14], in which the score is the sum of the squares of the three highest scoring injuries regardless of region. Modern battlefield blast fatalities have been shown to sustain injuries to multiple AIS regions.[15] This contrasts with previous data from World War II, and the Korean and Vietnam Wars, where the majority of combat fatalities were observed to have sustained only one life threatening 'hit'.[16] It has been argued that it is not possible to accurately determine the relative lethality of multiple potentially fatal~~lethal~~ injuries[17], and that in the context of battlefield trauma, injuries with an AIS≥4 have significant lethal potential.[13] We took these factors into account in devising our cause of death analysis methodology. Thus, equal weighting was given to all three injuries contributing to the NISS and we excluded any injuries with AIS≤3. This generated overall totals of potentially fatal~~lethal~~ injuries by AIS region. NISS was more appropriate than ISS given the frequency of multiple injuries to a single region in blast trauma, and because NISS has been shown to be a better predictor of mortality than ISS.[14]

> **Comment [JS5]:** As per EE's comments

> **Comment [JS6]:** As per EE's comments

We then assessed mechanism of death for every fatal injury (AIS≥4). We classified haemorrhagic injuries as extremity – amenable to tourniquet control- , junctional – potentially amenable to compression –, or intra-cavity – requiring surgical haemostasis. It was necessary to amalgamate anatomically separate groups into unifying mechanistic groups. This helped to clarify intra-group trends and facilitate inter-group comparison; we combined groin, neck and axillary haemorrhagic injuries to form an overall junctional haemorrhage group. Upper and lower limb haemorrhagic injuries constituted the extremity haemorrhage group. Intra-cranial, Intra-thoracic and intra-abdominal bleeds made up the intra-cavity haemorrhage group. Of note, only a single open head injury contributed to this group. Head and spinal neurological injuries, including contained intra-cranial bleeds, contributed to the CNS injury group.

> **Comment [JS7]:** Clarified as per NT and DS's comments

We performed statistical analysis using SPSS version 20.0 (IBM, Armonk, NY). For initial cohort comparison, we used the Mann-Whitney *U* (MWU) test to compare ages of the mounted (M) and dismounted (DM) groups - these variables were not normally distributed (testing for normality using the Shapiro-Wilk test generated a *p*-value of 0.023 for the M group and 0.001 for the DM group). We also compared time intervals, number of AIS regions sustaining lethal injury and total number of AIS regions injured per casualty using a Mann-Whitney *U* test, as these data sets were also non-parametric with Shapiro-Wilk *p*-values < 0.05. We used Fisher's exact test for inter-group comparison of specific causes of death and mechanism of death. A *p*-value < 0.05 was considered significant.

> **Comment [JS8]:** Added as statistical analysis on Fig 4 as per EE's comments

RESULTS

Study group composition

212 PM-CT fatality investigations were performed during the study period. This translated to a study group of 121 of which 42/121 were mounted (M) at time of wounding and 79/121 were in a dismounted (DM) environment when wounded (Figure 1).

Figure 1 - study group composition.

Initial cohort comparison

We found no significant differences between ages of the mounted and dismounted cohorts. 120 of 121 cases were male. The median interval from injury to scan for all 121 cases was 313 minutes (IQR 224-780), comprising median intervals of 81 minutes between injury and death, and 232 minutes from death to CT scan (further details in Table 1). The age profiles, wounding-death-scan intervals, KIA:DOW ratio and number of AIS regions with lethal injuries did not differ significantly between groups (Table 1). 62% (26/42) of mounted fatalities and 56% (44/79) of dismounted fatalities had potentially fatal injuries to two or more anatomical regions (≥2 AIS regions contributing to the NISS score).

Comment [JS9]: Added as per EE's comments

Table 1. Cohort comparison: Mounted vs. Dismounted

Group variable		Mounted (n=42)	Dismounted (n=79)	Overall (n=121)	M vs DM, *p* value
Age in yrs		25.5, (22-30)ᵞ	25.0, (21-29)ᵞ	25 (21-29)ᵞ	0.345
ToW* - ToD† in mins		78, (36-113)ᵞ	85, (58-196)ᵞ	81 (50-145)ᵞ	0.110
ToD – ToS‡ in mins		246, (160-714)ᵞ	216, (89-900)ᵞ	232 (105-712)ᵞ	0.234
KIA (%)		38 (90)	70 (89)	108	1.000
DOW (%)		4 (10)	9 (11)	13	1.000
Number of AIS regions with fatal injuries (%)	1	16 (38)	35 (44)	51	0.492
	2	22 (52)	38 (48)	60	
	≥3	4 (10)	6 (8)	10	

*time of wounding, †time of death, ‡time of scan, ᵞmedian (interquartile range)

Comment [JS10]: As per EE's request

Severity and anatomical burden of injury

Mounted fatalities had significantly higher NISS (p=0.012, MWU) values compared to dismounted fatalities indicating greater injury burden (Figure 2).

Figure 2 – NISS scores for mounted and dismounted fatalities

Mounted fatalities suffered injuries to significantly more AIS regions than dismounted fatalities with median values of 6 and 4 regions injured, respectively. (p<0.0001 MWU; Figure 3).

Figure 3 – AIS regions injured per fatality, mounted vs. dismounted

Cause and mechanism of death in blast fatalities

Clear differences were also evident in the anatomical distribution of fatal injuries in dismounted and mounted groups as shown in Table 2. Of note, 9/363 injuries making up the NISS scores were less than four, and were excluded from further analysis ,leaving 354 fatal injuries in total.

Table 2. Fatal injury rates by AIS region: Mounted (M) vs. Dismounted (DM)

AIS region	% of fatal injuries within group		M vs DM CoD rates, *p* value (Fishers)
	M (n=124)	DM (n=230)	
Head	53% (66)	19% (43)	<0.0001
Thorax	23% (29)	8% (18)	<0.0001
Lower extremity	7% (9)	48% (111)	<0.0001
Abdomen	8% (10)	13% (31)	0.1636
Neck	2% (2)	3% (8)	0.5039
Spine	4% (5)	3% (7)	0.7594
Other trauma	2% (2)	1% (3)	1.0000
Upper extremity	1% (1)	3% (7)	0.2695
Face	0% (0)	1% (2)	0.5435

Mechanism of death from these injuries was calculated, as previously described. The resultant chart is shown in Figure 4.

Figure 4 – Mechanism of death, mounted vs. dismounted

DISCUSSION

Fatal injury distribution and effect of environment on extent of injuries

Mounted and dismounted blast casualties presented here demonstrate significantly different potentially fatal injury profiles with respect to incidence of head, lower extremity and thoracic injuries (p<0.0001). Resultant mechanism of death also varied according to location at point of wounding. For mounted IED fatalities, CNS trauma, (most commonly severe traumatic brain injury (TBI) rather than spinal cord trauma) was the leading mechanism of death, followed by intra cavity haemorrhage. In dismounted IED fatalities haemorrhage predominated, most commonly from extremity bleeding, followed by junctional blood loss.

Comment [JS11]: As per EE's comments

This study also demonstrates that blast fatalities in vehicles are both more severely and more widely injured than dismounted blast fatalities. One might expect the vehicle to mitigate both the occupant's surface area affected by injurious components of the blast and the severity of injury sustained, but these hypotheses are not supported by our data. Clearly, type and size of IED will have a bearing on injury severity and distribution.[3 15] However, the sensitive nature of such munition data is self-evident and so any future work utilising such incident data would have to satisfy the understandable security issues.

Strengths and weaknesses

This is the largest series of IED fatalities reported to date with comprehensive CT and autopsy records. Studies such as this are invariably retrospective due to the constraints of battlefield trauma research, but meaningful analysis can still be performed – indeed there is an imperative to analyse fatality data to minimise future potential loss of life.

This study was based on injury data from the UK JTTR rather than solely PM-CT findings. All injuries noted at autopsy are stored in the UK JTTR. Furthermore, PM-CT results were available to the investigating pathologist; therefore the autopsy report can be considered a synergistic product of the radiological and physical investigations. Standard (i.e. non-contrast) PM-CT has inherent limitations - essentially decreased sensitivity for vascular and hollow visceral injuries compared to formal autopsy.[18] PM-CT angiography can redress this, but is an evolving science and is both time- and labour intensive compared to a standard CT scan, requiring invasive access to the femoral vessels, non-standard contrast media and a heart-lung bypass machine to temporarily restore circulation.[19] This would not be appropriate considering the clinical work load at the military hospital at Camp Bastion, Afghanistan where the PM-CTs are performed.

A potential weakness of PM-CT for trauma fatalities is loss of diagnostic sensitivity secondary to artefact either from resuscitation and/or decomposition. However, the autopsy was performed with the knowledge of any resuscitative procedures performed. Also, the median intervals between time of wounding and time of death were less than 90 minutes and those between time of death and time of scan were less than four hours,(and in cases with any significant delay to scan, the deceased were transferred to refrigerated mortuary conditions). Therefore, neither prior interventions nor decomposition artefact would have been likely to cause diagnostic issues in this study.

Comparisons with other studies

Such a comparison, as performed in our study, has not been presented previously for modern combat blast fatalities. To date, cause of death analyses for mounted and/or dismounted blast fatalities have tended to be reported with mounted fatalities as a separate group[15], as an amalgamated group[17], or amalgamated and in conjunction with other injury mechanisms such as gunshot wounds (GSWs), aircraft crashes and motor vehicle collisions (MVCs).[20]

Nelson *et al* reported a case series of 18 US military IED casualties injured in Iraq in 2004, of whom nine died.[21] Injuries were described in individual narratives, and were recorded clinically. No postmortem examination/imaging was reported. Of note, one of three mounted fatalities and four of six dismounted fatalities sustained severe head injuries. Our series also contained multiple cases of fatal head trauma, indicating this to be a consistent injury pattern amongst IED fatalities.

Farkash *et al* reported a case series of 22 Israeli Defence Force combat fatalities undergoing PM-CT from September 1997 and December 1998 following explosive trauma.[8] Formal autopsy is frequently opposed in Israel on religious grounds and only four cases underwent physical autopsy. Furthermore, extremities were not CT scanned in the Israeli group (head, neck, chest, abdomen, and pelvis only) and no summary injury severity data were presented. PMCT demonstrated injuries to the head/neck in 86% (19), f~~F~~ace 50% (11), c~~C~~hest 77% (17), a~~A~~bdomen 32% (7) and e~~E~~xtremities 36% (8). Without injury severity data, little further can be derived from this.

In 2011, Eastridge *et al* published their findings on~~looked at~~ cause of death in 558 died of wounds (DOW) US combat fatalities from Iraq and Afghanistan from October 2001 until June 2009, thus including both conventional warfighting and counter insurgency phases of combat.[22] Eastridge *et* *al* followed this up in 2012 with an analysis of 4596 US combat fatalities, of which 4016 were killed in action (KIA), again from Iraq and Afghanistan, from October 2001 until June 2011.[23] Data sources included peri-mortem medical records, autopsy reports and photos. PM-CT was not listed as a data source. Consistent with our methodology, when multiple wounds per casualty were noted, each wound was evaluated individually. There was no differentiation between mounted and dismounted fatalities in either study. and killed in action (KIA) cases were excluded, although Oof note in the DOW cohort, 232/558 cases were admitted to medical facilities in extremis with CPR in progress. Cases were classified as 'non-survivable' (NS, 271/558 DOW, 3040/4016 KIA) or 'potentially survivable' (PS, 287/558 DOW, 976/4016 KIA), nomenclature in keeping with previous US-led cause of death analyses.[20] Again, explosions were the main cause of injury (DOW 72%, KIA 74%) followed by GSWs (DOW 25%, KIA 22%), then other causes (DOW, MVCs (2%,) and helicopter crashes (1%, KIA 'other' (e.g. MVC, crush) 4%)). Both DOW and KIA groups showed TBI to be the predominant cause of death in their NS groups (83% and 45% respectively) and haemorrhage as the main causal mechanism in their PS groups (80% and 91% respectively)TBI was a cause of death in 83% of NS and 9% of PS cases, whilst haemorrhage was the causal mechanism in 16% of NS and 80% of PS cases. This concurs with our conclusions regarding research strategies most likely to decrease mortality from head trauma/TBI – prevention-orientated – and haemorrhage – improved haemostatic techniques at all levels of care. Subgroup data of lethal haemorrhage cases was only presented for PS cases but merits comparison with our study. We demonstrate a higher proportion of extremity haemorrhage cases as a proportion of all haemorrhage cases – 52% - then either the PS DOW group – 31% - or the PS KIA group – 13% - , similar rates of junctional haemorrhage – 27% in our study vs. 21% PS DOW and 19 % PS KIA – and a corresponding lower rate of intra-cavity haemorrhage – 21% vs. 48% PS DOW and 67% PS KIA). This may be explained in part by the presence of GSW cases in the DOW and KIA groups and the likely penetrating thoracoabdominal wounding pattern of significant numbers of these cases. The exclusion of KIA cases prevents further meaningful comparison with this study but serves to highlight an inherent difficulty with combat casualty data analysis –

truly differentiating between KIA and DOW cases, when multiple cases have arrived at medical facilities with ongoing CPR, is a complex task. We elected to analyse both KIA and DOW cases in order to capture the full spectrum of acutely fatal blast injuries.

Comment [SJ12]: Altered to include Eastridge et al's 2012 KIA paper as per NT's comments.

Studies by Bellamy in 1984 [16] and more recently by Champion et al in 2003 [24] presented summary data of all combat injuries sustained by US Marine and Army personnel in jungle combat in Vietnam from 1967-1969 based on clinical records and autopsy data. This database of 7,989 patients contains both survivors and fatalities and mounted and dismounted casualties. The majority were blast injuries (62% fragment, 3% (primary) blast) with 23% GSWs, 6% burns and 6% other mechanisms Champion showed a distribution of site of lethal injury as follows: 37% head, 24% chest, 9% abdomen, 3% extremity.. Interestingly, while this is initially similar to modern mounted blast fatalities (52% head, 25% chest, 8% abdomen, 8% extremity), Champion noted only 17% with multiple lethal injuries. Furthermore, Bellamy, analysing the same data, observed autopsy findings of multiple potentially fatal wounds in only 30 of 500 cases (6%). This contrasts markedly with our study group, in which 70/121 (58%) of cases sustained 2 or more potentially fatal injuries. In spite of the Vietnam data including GSW fatalities – more likely than blast casualties to sustain a single lethal injury - , the increased incidence of multiple lethal injuries per fatality in the modern data is likely to represent a real difference. This may reflect differing weapons systems responsible for the blast injuries, with greater relative use of conventional ordinance in Vietnam - artillery shells, mortars, grenades etc. – compared to IEDs, the sole injury mechanism in our series.

Such simultaneous commonality and difference emphasises the point that, in battlefield trauma analysis, comparisons between casualties from different theatres of war and certainly from different eras must be made with caution, as many factors including weapons systems, tactics, casualty evacuation and medical capabilities must be considered.

Future unexpected survivors

Blast CNS trauma tended to be of a severe blunt traumatic brain injury pattern and beyond redress with current medical management. Determining precise aetiology in mounted fatalities is complex, given victim exposure to multiple modalities with injurious potential. These include primary blast – the shockwave - , and tertiary blast at multiple instances as a vehicle is first accelerated upwards by the blast wind and then undergoes rapid deceleration on landing. Efforts to reduce mortality and morbidity from these devastating head injuries are likely to be most efficacious if concentrated on prevention and mitigation strategies, such as crew restraint and protection and improved helmet design against blunt trauma, rather than treatment after the blast.

Death in dismounted troops was most commonly due to haemorrhage, mainly from extremity, then junctional trauma. Our data suggest there is potential to decrease mortality thorough appropriately targeted haemostatic interventions such as compression *when possible* for these extremity and junctional injuries. There is good evidence that recent (2006 onwards), widespread adoption of pre-hospital tourniquet use for severe extremity haemorrhage from combat wounds has saved lives.[25] ~~Despite this,C~~civilian medical organisations have traditionally been ~~appear to remain~~ reluctant to add pre-hospital tourniquets to their armamentarium.[26] While indications for tourniquet use may be fewer in civilian trauma, the fact that they have been shown to improve survival following battlefield trauma highlights their potential to do the same in civilian trauma, in appropriate circumstances, and this appears to have been demonstrated by the emergency medical services' response following the Boston Marathon bombing.[23] It should also be noted that haemorrhage control continues to evolve. A US Food and Drug Administration approved junctional tourniquet, the Combat Ready Clamp (Combat Medical Systems, Fayetteville, NC) is currently being introduced in Afghanistan and truncal tourniquets have been stated as a US Department of Defense research priority.[27] The effective employment of such devices, if able to achieve pre-hospital haemostasis for blast casualties and others with haemorrhagic junctional trauma, clearly has the potential to improve survival rates.

Comment [JS13]: Amended and referenced as per NT and EEs comments

In contrast, the majority of mounted deaths from haemorrhage were due to intra-cavity haemorrhage, likely to have required surgical intervention too early (immediately or within minutes) to be feasible to provide in a contemporary combat environment. Recent operations in Afghanistan have shown casualty evacuation times from point of wounding to hospital of 75 minutes,[28] and this may be an emerging trend in more asymmetric conflicts. However, in more traditional scenarios such as the first Gulf War of 1991, the mean time taken from injury to arriving at a British surgical hospital was 10.2 hours and by the second Gulf War of 2003, with much shorter lines of communication and better casualty evacuation, the mean delay was still six hours.[29] This contrasts markedly with reports from the civilian environment. A study by Demetriades *et al* in 1996 of 5782 patients in California showed a mean interval of just 37 minutes from 911 call notification of emergency medical personnel to arrival at a trauma centre.[30] Therefore, even interventions with a brief or transient therapeutic window may be of benefit in improving the chances of getting a blast trauma patient with non-compressible bleeding to the surgical team alive. These may include pre-hospital adoption of haemostatic resuscitation techniques and use of novel pharmacological agents to prevent/reverse coagulopathy and certainly merit further study. This applies both to the military setting, where several such techniques are already employed or under review, and to civilian trauma, with potential applicability beyond blast trauma. However, the degree of benefit such techniques may confer to the general population, with a broader age range and greater pre-morbidity when compared to a military cohort, has yet to be determined.

Comment [SJ14]: In response to NTs comments.

CONCLUSIONS

IEDs are currently the main cause of death for deployed coalition troops and are likely to remain so for the foreseeable future. Worldwide, IED strikes are also common against civilians. In mounted fatalities following IED strikes, severe head injury was the main cause of death. Given the devastating nature of the associated traumatic brain injury, prevention and mitigation, rather than advances in medical treatment, are the most likely strategies to decrease mortality. Fatal haemorrhage in mounted casualties was most commonly intra-thoracic or intra-abdominal, currently only treatable surgically, with no effective pre-hospital intervention available.

This study has also shown that nearly two thirds of dismounted IED fatalities died from exsanguinating extremity or junctional haemorrhage, with lower limb the most common site. Maintaining the drive to improve all haemostatic techniques, from point of wounding to definitive surgical proximal control, alongside development and application of novel haemostatic devices and pharmacological agents could yield a significant survival benefit. This work and such techniques have relevance beyond military medicine to the many civilian trauma services that currently treat IED victims or may have to manage such cases in the future.

CONFLICTS OF INTEREST STATEMENT

All authors have completed the Unified Competing Interest form at www.icmje.org/coi_disclosure.pdf (available on request from the corresponding author) and declare that JS, IG, NH, AB and JC have no relationships with companies that might have an interest in the submitted work in the previous 3 years; their spouses, partners, or children have no financial relationships that may be relevant to the submitted work; and JS, IG, NH, AB and JC have no non-financial interests that may be relevant to the submitted work.

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study design, data interpretation, writing

All authors had full access to the all of the data, and can take responsibility for the integrity of the data and the accuracy of the data analysis.

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DISCLAIMER

The views expressed in this article are those of the authors and may not reflect the official policy or position of the UK Defence Medical Services or the Ministry of Defence.

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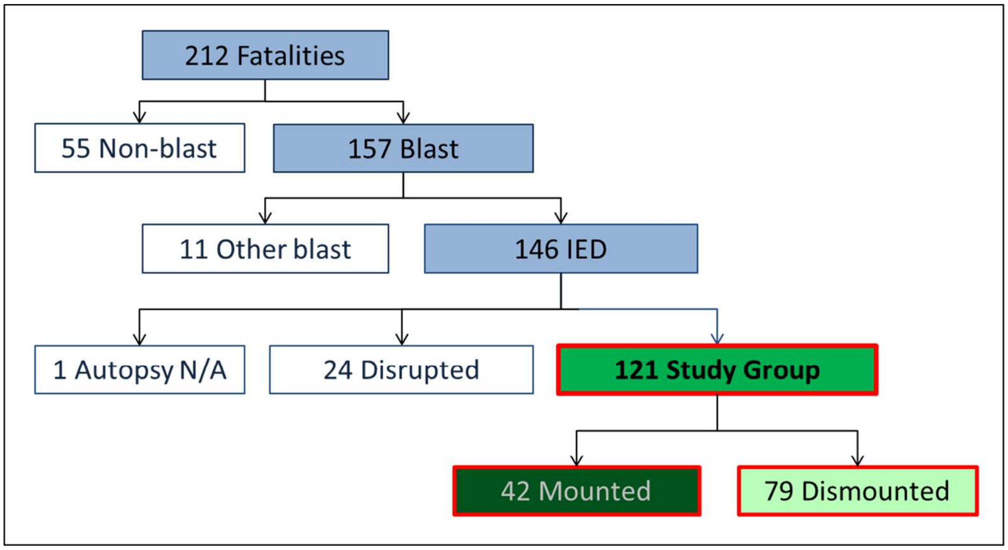

Figure 1 - study group composition
214x116mm (300 x 300 DPI)

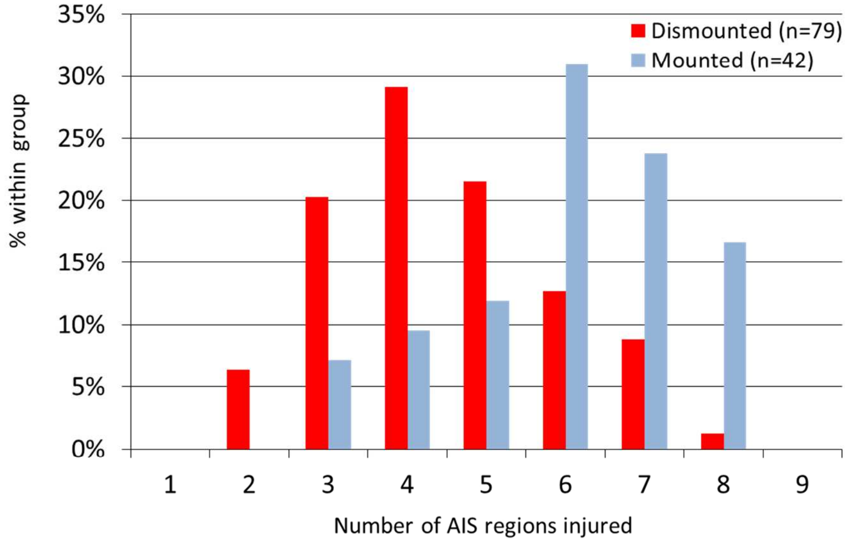

Figure 3 – AIS regions injured per fatality, mounted vs. dismounted
230x136mm (300 x 300 DPI)

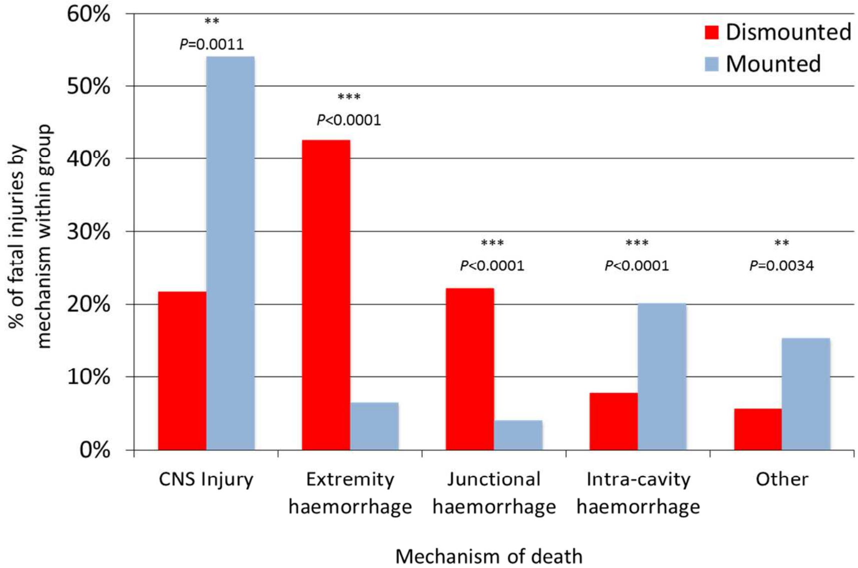

Figure 4 - Mechanism of death, mounted vs. dismounted
210x134mm (300 x 300 DPI)

Future ‘unexpected’ survivors – fatal injuries from IED blast trauma 2007-2010: retrospective cohort study

James A G Singleton, Iain E Gibb, Nicholas A C Hunt, Anthony M J Bull, Jon C Clasper

STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***

	Item No	Recommendation	Addressed
Title and abstract	1	(*a*) Indicate the study’s design with a commonly used term in the title or the abstract	Y
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	Y
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	Y
Objectives	3	State specific objectives, including any prespecified hypotheses	Y
Methods			
Study design	4	Present key elements of study design early in the paper	Y
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Y
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up	Y
		(*b*) For matched studies, give matching criteria and number of exposed and unexposed	N/A
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	Y
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	Y
Bias	9	Describe any efforts to address potential sources of bias	Y
Study size	10	Explain how the study size was arrived at	Y
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	Y
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	Y
		(*b*) Describe any methods used to examine subgroups and interactions	Y
		(*c*) Explain how missing data were addressed	N/A
		(*d*) If applicable, explain how loss to follow-up was addressed	N/A
		(*e*) Describe any sensitivity analyses	N/A
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	Y
		(b) Give reasons for non-participation at each stage	Y
		(c) Consider use of a flow diagram	Y
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic,	Y

		clinical, social) and information on exposures and potential confounders	
		(b) Indicate number of participants with missing data for each variable of interest	Y
		(c) Summarise follow-up time (eg, average and total amount)	N/A
Outcome data	15*	Report numbers of outcome events or summary measures over time	Y
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	Y
		(*b*) Report category boundaries when continuous variables were categorized	Y
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	N/A
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	Y
Discussion			
Key results	18	Summarise key results with reference to study objectives	Y
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	Y
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	Y
Generalisability	21	Discuss the generalisability (external validity) of the study results	Y
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	Y

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.