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ABSTRACT

Introduction: Explosions have caused a greater percentage of injuries in Iraq and Afghanistan than in any other large-scale conflict. Improvements in body armour and field medical care have improved survival and changed the injury profile of service personnel. This study's objective was to determine the nature, body region, and severity of injuries caused by an explosion episode in male service personnel.
Materials and methods: A descriptive analysis was conducted of 4623 combat explosion episodes in Iraq between March 2004 and December 2007. The Barell matrix was used to describe the nature and body regions of injuries due to a combat explosion.
Results: A total of 17,637 *International Classification of Diseases*, *Ninth Revision* (ICD-9) codes were assigned to the 4623 explosion episodes, with an average of 3.8 ICD-9 codes per episode. The most frequent single injury type was a mild traumatic brain injury (TBI; 10.8%). Other frequent injuries were open wounds in the lower extremity (8.8%) and open wounds of the face (8.2%), which includes tympanic membrane rupture. The extremities were the body regions most often injured (41.3%), followed by head and neck (37.4%) and torso (8.8%).
Conclusion: The results of this study support previous observations of TBI as a pre-eminent injury of the wars in Iraq and Afghanistan, with mild TBI as the most common single injury in this large cohort of explosion episodes. The extremities had the highest frequency of injuries for any one body region. The majority of the explosion episodes resulted in more than one injury, and the variety of injuries across nearly every body region and injury type suggests a complex nature of explosion injuries. Understanding the constellation of injuries commonly caused by explosions will assist in the mitigation, treatment, and rehabilitation of the effects of these injuries.

Introduction

The effects of explosions have caused a greater percentage of injuries in Operation Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF) than in any other large-scale conflict.[1] As of 28 May 2010, over 37,000 US service members have been wounded in action and over 4000 have been killed in action as a part of OIF and OEF.[2] The majority of these combat injuries and deaths are due to explosions,[3,4] which can cause a wide spectrum of injuries.[5] While there have been reports of specific injuries such as tympanic membrane injuries,[6] eye injuries,[7] burns,[8] and traumatic brain injuries,[9] as well as the constellation of injuries described as primary blast injuries,[10] there has been no comprehensive investigation into the type, location, and severity of injuries due to combat explosions.

Five different explosion injury mechanisms have been described.[5,11–13] These injury mechanisms do not occur in isolation and have the potential to impact multiple body systems.[5] Primary blast injuries are caused by an overpressurization shock wave followed by an underpressurization wave that travels through the body. Traumatic brain injury (TBI), lung injury, and tympanic membrane ruptures are caused by these shock waves.[5] Secondary injuries are created by bomb fragments and other fragments from the environment that are propelled by the explosion and are considered the most common cause of explosion-related injury.[11] The severity of these injuries can range from lacerations to

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traumatic amputations. Tertiary injuries are caused by a blast wind that can throw a victim to the ground as well as cause the collapse of buildings and other structures. Blunt and crushing injuries are common tertiary injuries. Quaternary blast injuries are all other injuries including burns and the inhalation of toxic substances released from the explosion. Quinary injuries are specific to additional elements found in a bomb, such as metals, fuels, radiation, and bacteria.

Champion et al. described the need for research in the epidemiology of wounds from explosions as well as the consequences of these injuries.[5] Advances in body armour have reduced the frequency of penetrating injuries, and improvements in field medical care have increased the survival rate in those experiencing explosions in combat. These advancements create a different combination of injuries in service personnel injured in explosions than seen in past conflicts,[13,14] thus, a comprehensive investigation of all explosion injuries is warranted to inform providers involved in trauma care and rehabilitation. The primary objective of this study is to describe the nature, body region, and severity of injuries caused by an explosion during combat in surviving male service personnel participating in OIF between March 2004 and December 2007. Individual demographics, injury circumstances (type of explosive device and use of personal protective equipment [PPE]), and the disposition of the service personnel after examination will also be explored.

Materials and methods

The Expeditionary Medical Encounter Database (EMED), formerly known as the Navy-Marine Corps Combat Trauma Registry, is a collection of data sets from multiple levels of care. The data for this study were primarily from frontline naval medical treatment facilities (MTFs) in Iraq as well as military hospitals outside of the continental United States and military hospitals within the continental United States.[15] The EMED includes data from both casualty medical records and clinical information collected during battle injury, nonbattle injury, and sick-call visits using the standard Department of Defense (DoD) medical record systems or paper records in remote areas with limited electronic connectivity. The medical record data are reviewed by EMED clinical staff at the Naval Health Research Center (NHRC), San Diego, CA, and both demographic information of the injured personnel and clinical information on the specific injury or illness are entered into the EMED database.

Clinical diagnosis codes from the *International Classification of Diseases*, *Ninth Revision* (ICD-9) were assigned to each injury described on the encounter form by trained and experienced clinical staff. If there are no documented injuries recorded on the encounter form, it is documented in the EMED that there were no injuries at that clinic visit. In addition to assigning diagnostic codes, severity of each injury is accessed using two different standardized injury severity measures, the Abbreviated Injury Scale (AIS) and the Injury Severity Score (ISS)[16] (version 2005). The AIS is an anatomically based injury severity scale, which scores each injury from 1 (minor) to 6 (unsurvivable) within six body regions (head, face, chest, abdomen, extremities, and external). The ISS is derived from the AIS score with a range of 0–75 and is an overall measure of injury severity. The ISS for each explosion episode was documented and categorized into one of four severity levels: mild (1–3), moderate (4–8), serious (9–15), and severe (16 and higher).

Between March 2004 and December 2007, there were 5091 explosion episodes involving 4774 male service personnel that resulted in an examination at a Level 1 or Level 2 MTF and an encounter form entered in the EMED. Female service personnel were excluded because of a low proportion in the sample. An explosion episode was defined as a documented mechanism of injury of an improvised explosive device (IED), grenade, rocket-propelled grenade (RPG), landmine, aerial bomb, or mortar. Of these 5091 encounters at an MTF, the 354 episodes that resulted in no documented injury and the 114 episodes resulting in the death of a service member, either at the initial site of care or a higher level of care were excluded. The final sample size for this study was 4623 episodes of combat explosions of service members who survived the blast, had a documented injury and an ICD-9 code assigned to that injury. This study was approved by the NHRC Institutional Review Board (Protocol NHRC.2009.0023).

Individual demographics (age, military rank, branch of service), injury circumstances (type of explosive device, year of explosion episode, PPE use), and disposition after clinic examination were ascertained for each explosion episode from the EMED database. Age was reported in years and calculated by the date of injury minus the date of birth. The date of the encounter at the Level 1 or Level 2 facility was used if the date of injury was not available. Military rank was categorized as junior enlisted (E1–E3), midlevel enlisted (E4–E5), senior enlisted (E6–E9), and officers/warrant officers. Military branch of service was categorized as Air Force, Army, Navy, and Marines.

The type of explosive device was categorized as IED, grenade, RPG, landmine, aerial bomb, or mortar. The year of the explosion was categorized as the year of the episode date. The year 2004 was only between March 2004 and December 2004, and all other years (2005–2007) were 12 full months. Multiple explosion episodes were defined as a repeat explosion episode in an individual. PPE use was defined as the documented use of any single PPE item as well as the specific use of helmet, flak jacket, ceramic plate, and eye protection. Disposition after examination was categorized as return to duty (RTD), light duty/sick in quarters (LD/SIQ), admission to MTF, or transfer to a higher level of care.

Data analysis

Means and standard deviations were reported for age and ISS across explosion episodes. Absolute numbers and percentages for the year of explosion event, mechanism of explosion event, PPE usage, multiple explosion exposure, and ISS levels were calculated. A one-way analysis of variance (ANOVA) was used to compare mean ISS between the different disposition statuses for the individual episodes, with a value of $p \leq 0.05$ considered significantly significant. Scheffe's correction was used for multiple comparisons.

The Barell injury diagnosis matrix was used to display the nature and body regions of injuries due to a combat explosion.[17] The standard matrix uses the ICD-9 codes that describe trauma, and constructs a matrix using 12 natures of injury (fractures, dislocations, sprains and strains, internal injuries, open wounds, amputations, injuries to blood vessels, contusions and superficial injuries, crush, burns, nerves, and unspecified injuries) and either 36, 12, or 5 body regions. The majority of the matrix cells include more than one ICD-9 code. Both the 36 body region and the 5 body region versions were used in the analysis. The 11 of the 12 injury natures were collapsed into orthopaedic injuries (fractures, dislocations, sprains and strains, amputations, crush injuries), internal injuries (internal, blood vessel injuries, nerve injuries), and surface injuries (open wounds, contusions and superficial injuries, burns). SAS software, version 9.2, was used for all data analysis (SAS Institute Inc., Cary, NC).

Results

The study population was composed of 4623 episodes of explosions that resulted in a survivable injury. Demographics of the injured personnel and explosion episode characteristics for each combat explosion episode are documented in Table 1. The average age of the personnel injured was 24 years, with a range of 18.3–58.7 years. The pay grade category with the highest episode proportion was junior enlisted (E1–E3) (41.7%), closely followed by midlevel enlisted (E4–E6) (39.8%). Marines had the highest proportion of episodes resulting in injury (75.9%), and the Army was second (18.7%).

Within the study period from March 2004 to December 2007, the majority of the episodes occurred in 2006, followed by 2005. IED was the most common explosion mechanism and was reported in 78% of the episodes. Any other single explosion mechanism was found in less than 10% of the episodes. There were 273 explosion episodes where the service personnel had experienced a previous explosion, with up to four separate explosion episodes per person. The use of at least one item of PPE (helmet, flak jacket, ceramic plate, eye protection) was documented in 88.8% of the episodes. In those who wore PPE, the use of helmet, flak jacket, and ceramic plate was at or above 90%, with 81% wearing eye protection (Table 1).

A total of 17,637 ICD-9 codes were assigned to the 4623 explosion episodes, with an average of 3.8 ICD-9 codes per explosion episode (range 1–40 codes) (data not shown). Seventy-two percent of all episodes reported more than one ICD-9 code. An AIS code was assigned to each documented injury, with a total ISS calculated for each blast episode. The average total ISS was 4.5, with a range of 1–75. Over 85% of the episodes resulted in mild-to-moderate severity as categorized by the total ISS (Table 1).

The most frequent disposition was service personnel transferred to a higher level of care after examination at the forward MTF (31.1%), followed by RTD (27.2%) and LD/SIQ (25.2%) (Table 2). ANOVA demonstrated a significant difference in mean total ISS between disposition status categories ($p < 0.001$). Post hoc analysis using Scheffe's method found that the mean ISS was highest in service personnel transferred to a higher level of care compared with all other disposition categories. The mean ISS for admission to the MTF was higher than RTD and LD/SIQ, which were not different than each other.

The Barell injury diagnosis matrix was used to categorize the ICD-9 codes by injury nature and body region. Table 3 displays the natures of injury and the body regions for single matrix cells with a percentage 1% or greater of the total number of ICD-9 codes. When examining single matrix cells within the full matrix (12 natures of injuries $\times$ 36 body regions), the most frequent injury was TBI Type 2 internal injury, which was 10.8% of all documented ICD-9 codes across all injury episodes. In the Barell methodology, TBI Type 2 is described as an injury with "no recorded evidence of intracranial injury, and a loss of consciousness of less than 1 h, or loss of consciousness of unknown duration, or unspecified level of consciousness".[16] The ICD-9 codes of that diagnosis matrix cell are consistent with a concussion (ICD-9 codes 850.0, 850.1, 850.5, 850.9). This is in contrast to TBI Type 1 which is a more serious TBI with documented intracranial injury or a more prolonged loss of consciousness. Other frequent injuries were open wounds in the lower extremity (8.8%); open wounds of the face (8.2%), which includes tympanic membrane rupture; and unspecified other head injuries (5.8%). All other single cells were less than 5% of total ICD-9 codes.

The figure summarizes the full matrix with three of the five standard body regions (head and neck, torso, and extremities) and combined injury nature categories (orthopaedic injuries, internal injuries, and surface injuries). The spine and back and unspecified by site body region categories were not included because of the relatively low percentage of injuries in these categories. When examining the body region and combined injury nature categories, surface injuries of the extremities were the most frequent injuries and were 27.6% of all documented ICD-9 codes. The extremities was the body region most often injured (41.3%), followed by head and neck injuries (37.4%), and torso (8.8%). Regarding the nature of

Table 1
Demographic and injury circumstances and severity among injured male service personnel per combat blast episode (n = 4623), Operation Iraqi Freedom, March 2004 to December 2007.

		Mean (SD)
Age (years)		24.5 (5.3)
	n[a]	%
Pay grade		
Junior enlisted	1927	41.7
Midlevel enlisted	1842	39.8
Senior enlisted	409	8.8
Officer/warrant	188	4.1
Branch of service		
Marines	3510	75.9
Army	866	18.7
Navy	241	5.2
Air Force	6	0.1
Type of blast		
IED	3612	78.1
Mortar	374	8.1
RPG	213	4.6
Grenade	190	4.1
Landmine	178	3.8
Rocket	53	1.1
Aerial bomb	3	0.1
Year of blast event		
2004[b]	904	19.5
2005	1313	28.4
2006	1784	38.6
2007	622	13.4
Multiple blast episodes	273	5.9
PPE documented	4104	88.8
Helmet[c]		
Worn	3788	92.3
Not worn	284	6.9
Flak jacket[c]		
Worn	3754	91.5
Not worn	270	6.6
Ceramic plate[c]		
Worn	3692	90.0
Not worn	270	6.6
Eye protection[c]		
Worn	3334	81.2
Not worn	613	14.9
Total ISS severity categories[d]		
Mild	2871	62.1
Moderate	1081	23.4
Serious	398	8.6
Severe	273	5.9

IED, improvised explosive device; ISS, Injury Severity Score; PPE, personal protective equipment; RPG, rocket-propelled grenade.
[a] Subject numbers for each variable do not add to total sample due to missing data.
[b] Year of 2004 is from March 2004 to December 2004.
[c] For each PPE, percentages worn/not worn reflect total PPE documented and do not add to total sample due to not documented/not applicable.
[d] Total ISS categories: mild 1–3, moderate 4–8, serious 9–15, severe ≥16.

Table 2
Disposition status and differences in total Injury Severity Score (ISS) between disposition status groups among injured male service personnel per combat blast episode (N = 4482)[a], Operation Iraqi Freedom, 2004–2007.

Discharge status	n (%)	Mean ISS (SD)[†]
Return to duty	1259 (27.2)	1.7 (1.2)
Light duty/sick in quarters	1162 (25.2)	2.4 (1.8)
Admit to MTF	624 (13.5)	3.7 (4.0)
Transfer higher level care	1437 (31.1)	9.1 (9.0)

MTF, medical treatment facility.
[a] Missing discharge status in 147 episodes.
[†] $p < 0.0001$, analysis of variance. Scheffe's test showed equal means between return to duty and light duty/sick in quarters; all other mean comparisons were significantly different.

Table 3
Frequency and percentage of IDC-9 codes ($n = 17{,}637$) (n (%)) out of total number of documented codes by body region and type of injury among injured male service personnel due to combat explosions, Operation Iraqi Freedom, 2004–2007.

	Fracture	Sprains/strains	Internal	Open wound	Contusion/superficial	Burns	Nerves	Unspecified
Type 1 TBI	[a]		297 (1.7)				[a]	
Type 2 TBI	[a]		1908 (10.8)					
Other head				198 (1.1)		[a]	320 (1.8)	1015 (5.8)
Face	392 (2.2)	[a]		1449 (8.2)		[a]		
Eye				289 (1.6)	373 (2.1)	[a]	[a]	
Neck	[a]	[a]		206 (1.2)		[a]	[a]	
Head/face/neck unspecified					676 (3.8)	[a]	[a]	[a]
Cervical VCI	[a]	180 (1.0)						
Chest	[a]	[a]	199 (1.1)	[a]	[a]	[a]	[a]	
Abdomen			216 (1.2)	[a]	[a]	[a]	[a]	
Pelvis	[a]	[a]	[a]	240 (1.4)	[a]	[a]	[a]	
Shoulder/upper arm	[a]	[a]		569 (3.2)	186 (1.1)	[a]		[a]
Forearm/elbow	234 (1.3)	[a]		489 (2.8)	[a]	[a]		
Wrist/hands/fingers	231 (1.3)	[a]		523 (3.0)	[a]	212 (1.2)		[a]
UE unspecified	[a]			[a]	[a]	[a]	177 (1.0)	[a]
Lower leg/ankle	488 (2.8)	[a]			[a]	[a]		
Foot/toes	275 (1.6)	[a]		[a]	[a]	[a]		
LE unspecified	[a]	[a]		1555 (8.8)	302 (1.7)	[a]		[a]
Unspecified site	[a]	[a]	[a]	[a]	[a]	253 (1.4)	[a]	[a]

LE, lower extremity; TBI, traumatic brain injury. Body regions (Type 3 TBI, spinal cord injury, vertebral column injury except for cervical vertebral column, trunk, back and buttocks, upper extremity unspecified, hip, upper leg and thigh, knee, other/multiple sites, systemwide or late effects) and injury types (dislocation, amputations, blood vessels, crush) with injuries ≤1% are not shown.
[a] Cells with <1% injuries.

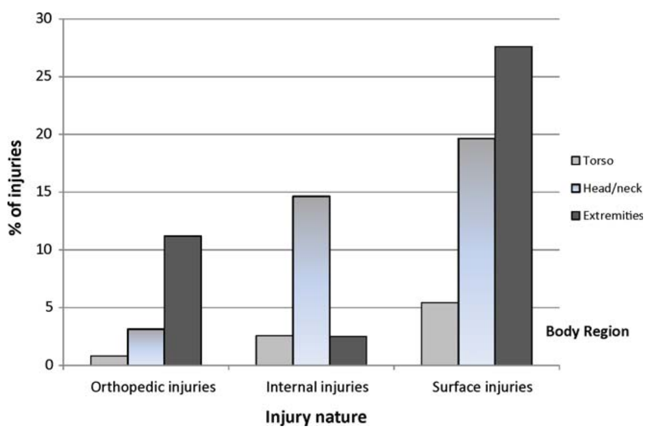

Fig. 1. Percentage of injuries distributed by the nature of the injury and body region. Orthopaedic injuries include fractures, dislocations, sprains and strains, amputations, and crush injuries. Internal injuries include internal injuries, blood vessel injuries, and nerve injuries. Surface injuries include open wounds, contusions and superficial injuries, and burns. The body regions of spine and back and unspecified site were excluded from the figure because of the low percentage of injuries.

injury, surface injuries were most frequent (52.7%), followed by internal injuries (19.7%) and orthopaedic injuries (15.1%) (Fig. 1).

Discussion

With the large proportion of injuries caused by explosions in the current military conflicts and the changing injury profiles from improved body armour and frontline medical care, understanding the scope of injuries due to explosions will improve the mitigation, treatment, and rehabilitation of combat explosion consequences in survivors. This comprehensive report of all injuries resulting from 4623 combat explosion episodes is unique because data are used from Level 1 and 2 MTFs in Iraq and all levels of severity, including data on those who returned to duty after an initial examination at these MTFs.

The results of this descriptive study support previous observations of TBI as a pre-eminent injury of the Iraq and Afghanistan wars.[18] Nearly 11% of all the documented ICD-9 codes among the injury episodes were described as TBI Type 2 internal injury, which is consistent with a mild TBI or concussion. While civilian reports suggest that the majority of individuals with mild TBI recover within 3 months,[19] mild TBI has recently been associated with a vast array of negative outcomes in military personnel, including mental health disorders and separation from service for behavioural reasons.[20,21] Additionally, over 40% of the ICD-9 codes documented injuries to the extremities, which is consistent with other combat wound reports as well as injuries from explosions alone.[1,22,23] The most frequent injury to the extremities was open wounds, accounting for over 18% of all injuries. While improved body armour has reduced injuries to the torso,[1] the extremities are still vulnerable. The high PPE compliance rates among the study population were encouraging, and likely represent strict enforcement of these safety guidelines in combat theatre.

Injuries from explosive devices are due to multiple mechanisms that are evident in the wide variety of injuries reported in these explosion events and injuries across multiple body regions and organ systems.[5,22] Injuries were present in nearly every body region and nature of injury within the Barell injury diagnosis matrix, and more than one ICD-9 code was reported in over 70% of the episodes in this cohort, with an average diagnosis count of nearly four per explosion episode. Polytrauma has been defined by the Veterans Health Administration as "...two or more injuries sustained in the same incident that affect multiple body parts or organ systems and result in physical, cognitive, psychological or psychosocial impairments and functional disabilities".[24] TBI is a frequent component of polytrauma, and the impairments from TBI often are the focus of rehabilitation. Specific rehabilitation challenges in polytrauma treatment have been identified and systems of care are being established to address these challenges.[14,24–26]

The primary limitation of this study and any other military specific study which relies upon the ICD-9 and AIS coding taxonomies is that these taxonomies have been developed and normalized upon civilian trauma. Therefore, they fail to adequately reflect combat-specific injuries particularly with regards to massive soft-tissue defects; avulsions and loss of cranial contents; non-compressible junctional vessel injuries; or burn to specific body regions typically seen in combat injuries. This is an increasingly recognized concern within military medicine and is currently being addressed by a DoD working group.

In addition, nearly 6% of the ICD-9 codes fall into the ''unspecified'' category, which is often used if there is not enough information in the record to give a more detailed code. In the presence of serious injuries, minor injuries many not be documented in injured service personnel because of the importance of treating the serious injury. Missing records can occur for various reasons including not visiting an MTF for care, rapid evacuation with limited documentation time, and incomplete coverage of all MTFs in the EMED. Since the MTFs covered are primarily Navy-Marine Corps facilities, Army personnel are underrepresented in the study population. Lastly, given the absence of autopsy data for those who were evaluated at a Level 1 or Level 2 MTF, all service personnel who subsequently died of their wounds were not included in this report.

A primary strength of the present study is the large sample of combat explosion episodes, which include data across a wide range of injury severities and from all levels of care, thus creating a unique opportunity to describe the effects of explosions. With frontline MTF data, minor injuries are better represented for service personnel who are returned to duty or placed on light duty after medical evaluation. The use of the Barell injury diagnosis matrix on these data goes beyond assessing a single injury type, determining a primary diagnosis, or evaluating severity scores.[27] This method provides a more comprehensive approach to examining both the body region and the nature of the multiple injuries of these explosion episodes, although it does not provide incidence data for any single diagnosis.

Conclusion

The most common single injury in the cohort of 4632 injuries from combat explosions was a TBI Type 2 internal injury, which is consistent with a concussion. When the body region and nature of injury were collapsed into broader categories, surface wounds of the extremities were the most common injuries. Understanding the nature and body region of injuries due to combat explosions will assist in providing adequate PPE and inform clinicians who are providing care for wounded service personnel. In addition, investigations into the long-term physical and psychosocial effects of these injuries are necessary to guide medical management after injury.

Conflict of interest statement

Authors report no conflict of interest. The authors alone are responsible for the content and writing of this paper.

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14. ABSTRACT

Combat-related blasts have caused large percentages of injuries in Iraq, and improvements in body armor and field medical care have improved survival and changed service personnel's injury profile. This study's objective is to describe the nature, body region, and severity of these injuries. A descriptive analysis was conducted of 4623 combat-related blast episodes in Iraq. The most frequent single injury type was mild traumatic brain injury (TBI; 10.8%). Other frequent injuries were open wounds in the lower extremity (8.8%) and open wounds of the face (8.2%). The extremities was the body region most often injured (41.3%), followed by head and neck injuries (37.4%) and torso (8.8%).
These results support previous observations of TBI as a preeminent injury of the Iraq and Afghanistan wars, with mild TBI as the most common single injury in this cohort of blast episodes. The variety of injuries across nearly every body region and injury type suggests a complex nature of blast injuries. Understanding the constellation of injuries commonly caused by combat-related blasts will assist in the mitigation, treatment, and rehabilitation of these injuries.

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