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Retrospective Case Series of US Service Members Medically Evacuated from Operations Enduring Freedom, Iraqi Freedom, and New Dawn with Blast-Related Head and Facial Injuries

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Abstract

The head and face remain one of the most difficult areas to protect from combat injuries while allowing Service members to maintain situational awareness. The following analysis describes the epidemiology of primary, secondary, tertiary, and quaternary blast-related head and facial injuries in US Service members medically evacuated to a combat support hospital during Operations Enduring Freedom, Iraqi Freedom, and New Dawn. De-identified Department of Defense trauma registry data from March 2002 through December 2011 were obtained and analyzed for this retrospective case study. Frequency distributions were tabulated for categorical variables describing demographic and injury characteristics. Results indicated that of 8,824 US Service members medically evacuated with head and/or facial injuries, 92% (n = 8,113) involved explosive devices. Moreover, of the 18,761 blast-related head and facial injuries diagnosed overall, traumatic brain and facial injuries comprised 75% by body part injured (brain, ear, face, and/or eye). Intracranial injuries, open wounds, and fractures comprised 92% by nature of injury. The conclusion, determined from the cause of injury recorded in trauma registry records, is that explosive devices were the predominant cause of head and facial injuries among deployed US Service members, suggesting improved blast protection is needed.

Keywords: *blast injury; facial injury; traumatic brain injury*

Introduction

Blast-related head and facial injuries comprise a significant percentage of combat injuries sustained by US Service members (SMs) during Operations Enduring Freedom (OEF), Iraqi Freedom (OIF), and New Dawn (OND) [1]. Blast-related injury occurs from proximity to the detonation of explosive devices including improvised explosive devices (IEDs), person borne explosive devices, vehicle borne devices, and rocket-propelled grenades (RPGs). Primary blast injuries (PBI) are the result of the blast waves created upon detonation of explosive devices, causing air pressure changes that can rupture eardrums, the most common of these injuries. Secondary blast injuries are the result of projectile fragments and debris picked up by the blast wave or emitted from the explosive device itself, often penetrating and/or embedding in skin and other exposed tissue. The impact of a projectile force on the eye is concentrated over a very small surface area when compared to a similar impact on other body parts, thus making impact particularly injurious to the eye [2]. Tertiary blast injuries (e.g. concussions or other blunt force trauma), result from the force of blast waves causing the body to impact other objects. Finally, quaternary blast injuries, e.g. burns, result from the effects of heat and chemicals released by the explosive device.

The US Army issues Personal Protective Equipment (PPE) to its Soldiers. PPE includes the Advanced Combat Helmet (ACH), Combat Arms Ear Plug (CAE), and Military Combat Eye Protection (MCEP) [3] to help protect Soldiers from blunt impact, noise, and ballistic exposures to the head, ears, and eyes in the combat environment. Both the US Air Force and US Navy issue MCEP to deployed Airmen and Sailors, respectively. The US Marine Corps issue a set of PPE known as the Family of Ballistic Protective Systems to each deployed Marine, which includes ballistic vests, armor plating, protective helmet, and eye/ear protection [4].

The DoD Joint Trauma System (JTS), administered by the US Army Institute of Surgical Research (USAISR), was modeled after US civilian trauma systems to better organize and coordinate the delivery of combat casualty care [5]. Trauma inpatient admissions to Role 3 or higher medical treatment facilities (MTFs) within a JTS are recorded in the Department of Defense Trauma Registry (DoDTR), previously the Joint Theater Trauma Registry, the largest combat injury database known at this writing. DoDTR uses the Abbreviated Injury Scale (AIS), to code injury diagnoses; after which the Injury Severity Score (ISS) is used to quantify the severity of multiple injuries of individual patients [6,7].

First devised in the 1970s and revised in 2005, the AIS is an anatomically based global severity scoring system used to classify injury by body region, utilizing a six-point scale. Each anatomic injury is assigned a six-digit numeric code indicating the anatomic location, type, and extent of injury, and a severity score from one to six [6]. For multiple trauma injuries, the ISS is used to calculate the overall severity for up to three anatomical regions. Eye, ear, and facial injuries are coded within the facial region of the AIS dictionary; brain and skull injuries are coded within the head region [6]. In describing the blast-related head and facial injuries sustained in OEF, OIF, and OND, DoDTR records were analyzed retrospectively to generate a case study focusing on head and/or facial injuries suffered by SMs who required evacuation and treatment within the JTS. In this article, we describe the epidemiology of these injuries with respect to the demographics of the SMs who sustained these injuries, the causes, frequencies, and severities of these injuries, and the level of comorbidity of these injuries. PPE use was made in the prevention and mediation of these injuries. While similar studies of blast-related injuries from OEF and OIF have been completed by the Naval Health Research Center (NHRC), those studies analyzed records from the Expeditionary Medical and Encounter Database (EMED), previously the Navy-Marine Corps Combat Registry, and were comprised of a population that was predominantly US Marines; therefore, the results may not be generalizable to the other branches of the Armed Services. The present study replicated previous studies but utilized a different dataset (i.e. one comprised predominantly of US Army Soldiers with different operational and PPE requirements).

Methods

USAISR obtained an extract of DoDTR data that contained de-identified data concerning SMs who had sustained eye, ear, face, and/or brain injuries between March 2002 and December 2011. The US Army Medical Research and Material Command (USAMRMC) Human Research Protections Office (HRPO) determined this Request For Information (RFI) did not rise to the level of human subject research.

Using the SAS® statistical software package, version 9.1 (SAS Institute, Cary, NC), three filters were applied to these data to obtain a case population. The filters are as follows: filter 1-records were selected based on injuries sustained during combat operations; filter 2-records that indicated the following explosive devices as the cause of injury were selected: aerial bomb, explosively-formed penetrator (EFP), IED, hand grenade, mine/landmine, motor/rocket/artillery shell, multi-fragment, RPG, unexploded ordnance (UXO), or explosives not otherwise previously specified. The demographic characteristics of this case population, and the causes, types, frequencies, and severities of blast-related injuries were analyzed by body part injured; and filter 3-data for blast-related head and facial injuries (e.g. brain, ears, face, eye/s) were isolated within the data and analyzed for this review.

Currently, injuries to the ears and eyes are subsets of facial injuries in the AIS dictionary; thus, the subsets were analyzed separately. Each corresponding AIS code assigned to an injury diagnosis code ranged from 800 to 995 within the International Classification of Diseases, Ninth Revision Clinical Modification (ICD-9-CM). The ICD-9-CM is an international disease injury classification system adapted for use in the US to code physical diagnoses and medical procedures. By using the ICD-9-CM injury diagnosis code provided in the DoDTR data, the authors were able to code the injury data into a Barell Injury Diagnosis Matrix.8 In order to better analyze the ICD-9-CM codes, injury data using standardized, clinically meaningful diagnostic categories were examined in a two-dimensional matrix. This matrix was modified to allow cross-tabulation of the body part injured (brain, ear, face, and eye) by nature of injury (fracture, internal, open wound, contusion, burn, dislocation) to better characterize the pattern of blast-related head and facial injuries sustained in the case population occuring in OEF, OIF, and OND. To calculate annual case rate, the number of SMs deployed per month for OIF, OND (Iraq only), and OEF (Afghanistan only) were obtained from the Defense Manpower Data Center (DMDC) and averaged for each military operation and calendar year. For each military operation, annual cases were divided by the average monthly deployed SM count based on the calendar year and multiplied by 100,000. Of this case population, 20% sustained 1,688 AIS-coded blast-related ear injuries, of which 91% were tympanic membrane ruptures, the second most common AIS-coded injury in this analysis. Fifty-three percent of these SMs also sustained a traumatic brain injury (TBI). Unlike SMs who suffered other blast-related head or facial injuries, a significantly higher percentage of SMs with ear injuries were dismounted (41% vs. 35%). Because the AIS is an anatomically based injury severity scoring system, it does not take into account functional impairment (such as hearing loss) from injury, but rather describes injuries, which is one of its disadvantages; the maximum AIS score for the ear is 2. Other measures, such as the Glasgow Coma Scale for measuring central nervous system function and the Functional Capacity Index, attempt to describe functional impairment from injury.

Case population

Of the case population, 5,629 SMs (69%) sustained a total of 7,703 AIS-coded blast-related TBIs. Thirty percent of these TBIs were determined to be type I; 70% were determined to be type II. The mean ISS was 24.0 among SMs with type I TBI and 9.3 among SMs with type II TBI. The mortality rate was 15% among those with type I TBI and 1% among those with type II TBI.

Facial injuries

Forty-four percent sustained a total of 6,362 total AIS-coded blast related facial injuries. Approximately 3,593 (56%) suffered open wounds, and 2,779 (44%) of those were facial fractures. Half of these SMs also sustained a TBI, and penetrating injuries and lacerations made up 79% of open facial wounds. Moreover, fractures of the facial bones comprised 2,779 of the total 6,362 facial injuries (44%). Fractures of the facial bones were more severe than were open wounds of the face (AIS = 1.8 out of 4 vs. 1.0 out of 4). Given the limitation of the ISS scoring system, comparing injury score to injury score within different body regions can be difficult.

Eye injuries

Twenty percent of the SMs in this study sustained a total of 3,008 AIS-coded blast-related eye injuries. Of those injuries, 50% were open wounds, 48% were contusions, and 2% were burns or nerve injuries. Because these injuries alone were not life-threatening, each individual eye injury was assigned an AIS severity score of 1, 2, or 3 (maximum) indicating significant injuries based on the injury. Because the AIS-coded scores do not account for functional impairment from eye injury, Duma [9] developed an alternative eye injury severity scale that accounts for a given injury's potential for vision loss and/or need for surgery. Accordingly, each eye injury AIS-code and corresponding ICD-9 diagnosis code were assigned one of the following four severity levels: level I, signifying the least severe injuries, including minor injuries to the eyelid or orbit area soft tissue; level II, including minor injuries to the eye itself; level III, including eye injuries having greater potential for vision loss and/or need for surgery, and finally; level IV, signifying catastrophic eye injuries resulting in vision loss [2,9]. Using this alternative eye injury severity scale, 65% of the 3,820 AIS-coded eye injuries sustained were assigned level III or IV. The most common eye injuries on each severity level were: level I, lacerations of the eyelid or periocular area (*n* = 11); level II, corneal abrasions (*n* = 525); level III, orbital fractures (*n* = 812); and level IV, scleral lacerations or ruptures (*n* = 544). In total, these injuries comprise 50% of all blast-related eye injuries.

Of the 1,604 Soldiers in this study who sustained blast-related eye injuries, 71% also sustained facial injuries. Of particular interest, 343 SMs who sustained an orbital or a maxillary fracture suffered no eye injury. One possible explanation is that they had used MCEP at the time of the blast exposure; however, it is possible to suffer orbital injury without injury to the eye itself. Also, of those 343 SMs, 68% sustained a TBI and 21% also sustained injury to the ear. These rates were plotted by military operation and calendar year using Microsoft® Excel.

Results

Of the 8,824 SMs medically evacuated from combat with head or facial injuries in the above-named deployments, 92% (*n* = 8,113) were injured by the above-named explosive devices, 6% (*n* = 571) were injured by firearms, and 2% (*n* = 140) were injured by other mechanisms. Because 92% of these injuries were associated with the explosive devices named above, this analysis focused only on those SMs who sustained blast-related head or facial injuries from these specified devices. Table 1 illustrates the demographic and injury characteristics of those SMs having sustained blast-related and/or facial injuries; 58% were injured in OIF/OND. Of that group, 72% were US Army Soldiers and 25% were Marines. Of those groups, 98% were male, 51% were mounted (inside a vehicle), and 27% were dismounted (external to a motor vehicle). Of the total number of injured (*N* = 8,113), nearly 70% sustained TBI, 43% facial injury, 20% ear injury, and 20% eye injury. These injury totals are not mutually exclusive. Thirty-nine percent of SMs evacuated suffered injuries to more than one body part (brain, ear, face, and/or eye). Twenty-one percent had a composite ISS of 16 or greater, indicating severe injury. Finally, a higher percentage of those with ISS scores equaling 16 or greater were deceased at final discharge (3.2%) when compared to those with other blast-related injuries. Table 1 illustrates blast-related head and facial injury cases per 100,000 deployed SMs for OIF, OND, and OEF by calendar year. In 2004, the case rate peaked (1,390 per 100,000) in deployed SMs in OIF and OND. The OEF case rate plateaued at 1,214 cases per 100,000 in 2009 and 1,219 cases in 2010. Table 1 also illustrates these injuries (TBI, ear, facial, eye) across all Service branches (Army, Marines, Navy, Air Force, Coast Guard), as well as gender and mounted status, if known. Finally, Table 2 summarizes the total numbers and percentages of SMs receiving these injuries.

Demographics					
Military Operation	**Total *n* (%)**	**TBI *n* (%)**	**Ear *n* (%)**	**Facial *n* (%)**	**Eye *n* (%)**
OIF/OND	4,673 (58%)	2,706 (48%)	987 (61%)	2,413 (76%)	1,097 (68%)
OEF	3,440 (42%)	2,923 (52%)	643 (39%)	1,187 (33%)	507 (32%)
Service					
Army	5,848 (72%)	4,035 (72%)	1,099 (67%)	2,677 (74%)	1,156 (72%)
Marines	1,999 (25%)	1,422 (25%)	465 (29%)	794 (22%)	379 (24%)
Navy	158 (2%)	104 (2%)	37 (2%)	75 (2%)	38 (2%)
Air Force	107 (1%)	67 (1%)	29 (2%)	54 (2%)	30 (2%)
Coast Guard	1 (< 1%)	1 (> 1%)	0 (0%)	0 (0%)	1 (< 1%)
Gender					
Male	7,987 (98%)	5,558 (99%)	1,605 (98%)	3,536 (98%)	1,577 (98%)
Female	126 (2%)	71 (1%)	25 (2%)	64 (2%)	27 (2%)

Mounted Status					
Mounted	4,116 (51%)	3,084 (54%)	577 (35%)	1,699 (47%)	671 (42%)
Dismounted	2,159 (27%)	1,544 (27%)	666 (41%)	889 (25%)	450 (28%)
Aviation	12 (< 1%)	8 (< 1%)	2 (< 1%)	8 (< 1%)	1 (< 1%)
Boat	2 (< 1%)	1 (< 1%)	1 (< 1%)	0 (0%)	2 (< 1%)
Unknown	1,824 (22%)	1,028 (18%)	384 (24%)	1,004 (28%)	480 (30%)

Table 1: *Demographic and injury variables of US SMs (N = 8,113) with blast head and/or facial injuries medically evacuated from OEF, OIF, and OND to a JTS medical treatment facility, 2002–2011.*

Of the 8,113 SMs who sustained AIS-coded blast-related head and facial injuries, the top three injuries were: 1,602 cerebral concussions with brief loss of consciousness, 1,537 tympanic membrane ruptures, and 1,158 facial penetration injuries. Table 3 illustrates the mean AIS-coded severity scores of the injuries. The possible AIS-coded severity score ranges for each injured body part include: brain, 1-6; ear, 1-6; face, 1-4; and eye, 1-3. When compared to possible score ranges for other injured body parts, the range of possible scores for brain injury is broader, with 32% receiving AIS scores of 3 or higher, indicating a relatively greater severe injury and threat to survival. Therefore, an average AIS score of 2.2 for TBI was comparatively higher, given type of injury, than for other body parts, due to the assumptions of the AIS scoring system.

Frequency of injury					
Body part injured	**Total *n* (%)**	**TBI *n* (%)**	**Ear *n* (%)**	**Facial *n* (%)**	**Eye *n* (%)**
TBI	5,629 (69%)	5,629 (100%)	859 (53%)	1,794 (50%)	757 (47%)
Ear	1,630 (20%)	859 (15%)	1,630 (100%)	776 (22%)	419 (26%)
Face	3,522 (43%)	1,743 (31%)	751 (46%)	3,600 (100%)	1,132 (71%)
Eye	1,766 (22%)	876 (16%)	456 (28%)	1,132 (31%)	1,604 (100%)
Injury Severity Score					
1–15	6,369 (78%)	4,301 (76%)	1,230 (76%)	2,540 (71%)	1,125 (70%)
16–25	1,081 (13%)	804 (14%)	280 (17%)	681 (19%)	1,125 (18%)
26–50	619 (8%)	490 (9%)	115 (9%)	363 (10%)	173 (11%)
51–75	44 (1%)	34 (1%)	5 (< 1%)	16 (< 1%)	13 (1%)
Final disposition					
Alive	7,895 (97%)	5,463 (97%)	1,619 (99%)	3.504 (97%)	1,552 (97%)
Deceased	218 (3%)	166 (3%)	11 (1%)	96 (3%)	52 (3%)

Table 2: *Composite ISS range from 1 (minor) to 75 (most severe) reflecting person-level data, and the person's final disposition (at time of final discharge).*

As illustrated in Table 2, composite ISS range from 1 (minor) to 75 (most severe). The data shown in Table 2 reflect person-level data, not injury-level data (one person can have more than one injury); the person's final disposition (at time of final discharge) is also shown.

Table 3 illustrates the cross-classification of the 18,761 total blast-related head and face injuries sustained by the 8,113 SMs, by body part injured and nature of injury. TBI and facial injury comprised 75% of all blast-related head and facial injuries by body part. Internal head injuries, open wounds of the ear, face, and/or eye, as well as fractures of the skull or facial bones comprised 92% of all blast-related head and facial injuries by nature of injury.

AIS-coded injury scores					
	Total *n* (%)	**TBI *n* (%)**	**Ear *n* (%)**	**Facial *n* (%)**	**Eye *n* (%)**
Minor	10,135 (54%)	2,2658 (29%)	1,652 (98%)	3,910 (61%)	2,305 (77%)
Moderate	6,089 (32)	2,950 (38%)	36 (2%)	2,402 (38%)	701 (23%)
Serious	1,674 (9%)	1,631 (21%)	0 (0%)	41 (1%)	2 (< 1%)
Severe	555 (3%)	546 (7%)	0 (0%)	9 (< 1%)	0 (0%)
Critical	297 (2%)	297 (4%)	0 (0%)	0 (0%)	0 (0%)
Maximal	11 (< 1%)	11 (< 1%)	0 (0%)	0 (0%)	0 (0%)
Mean	1.7	2.2	1.0	1.4	1.2

Table 3: *Table 3: AIS-coded injury scores by severity and head region.*

Traumatic Brain Injuries

The Barell Matrix (Table 4) classifies TBI by three types. Type 1 injuries include the recorded evidence of intracranial injury or prolonged loss of consciousness, as well as damage to eye and optic nerve. Type 2 injuries have no recorded evidence of intracranial injury; however, they did have a loss of consciousness of less than 1 hour, or of unknown duration or unspecified level of consciousness based on the description. Type 3 injuries have no evidence of either intracranial injury or loss of consciousness. It should be noted that the duration of the loss of consciousness is significant, for the longer the loss of consciousness, the more severe the post TBI symptoms, and the higher the likelihood of prolonged effects such as increased recovery time or more persistent symptoms may result.

Body Part	**Total**	**Fracture**	**Intetrnal**	**Open**	**Contusion**	**Burn**	**Dislocation**	**Nerve**
Injured				**Wound**				
TBI Type 1	2,330	225	2,105	--	--	--	--	--
TBI Type 2	5,373	620	4,753	--	--	--	--	--
Ear	1,688	--	--	1,657	--	--	--	31
Face	6,362	2,779	--	3,554	--	11	18	--
Eye	3,008	--	--	1,501	1,430	37	--	40
Total Inj.	18,761	3,624	6,858	6,712	1,430	48	18	71
Body Part								
Injured %								
TBI Type 1	12	6	31	--	--	--	--	--
TBI Type 2	29	17	69	--	--	--	--	--
Ear	9	--	--	25	--	--	--	44
Face	34	77	--	53	--	23	100	--
Eye	16	--	--	22	100	77	--	56
Total Inj.	100	100	100	100	100	100	100	100

Nature of								
Injury %								
TBI Type 1	100	10	90	--	--	--	--	--
TBI Type 2	100	12	88	--	--	--	--	--
Ear	100	--	--	98	--	--	--	2
Face	100	44	--	56	--	< 1	< 1	--
Eye	100	--	--	50	48	1	--	1
Total Inj.	100	19	37	36	8	< 1	< 1	< 1

Table 4: *Cross-classification of the 18,761 total blast-related head and facial injuries sustained by the 8,113 SMs, by body part injured and nature of injury and AIS-coded injury scores.*

Discussion

The pattern of blast-related head and facial injuries seen in this retrospective study were the result of blast effects that resulted in primary, secondary, tertiary, and quaternary blast injuries. Given the susceptibility of the eardrum to PBI from blast overpressure, it should be noted that tympanic membrane rupture remained the second most common AIS-coded injury in this study. Moreover, tympanic membrane rupture has been identified as a marker of concussion among SMs in OIF [1,10,11].

Whether or not blast-related eye injuries occur as a result of primary or secondary blast effects or a combination remains a matter of debate [12,14]. Although the eye can rupture from a blast percussion wave, only two cases of pure PBI to the human eye have been reported in the clinical medical literature since 1992 [11,12, 13,14]. The use of eye protection has reduced injury by protecting the eyes against open penetrating injuries, closed, non-penetrating injuries of the eyes from blast wave exposures are an increasing concern, as these injuries often go undiagnosed and may be associated with TBI [15]. Blowout fractures of orbital walls have been observed in animal models at blast overpressures above 140 lb/in [2]., with time to peak pressure less than 30 ms [14]; similar blowout effects are common in humans. In this analysis of blast-related head and facial injury patterns, facial penetration injury was the common, while orbital fracture was the most common type of facial fracture. For this study, 32% of SMs who had sustained an orbital fracture also sustained scleral lacerations or ruptures. It is unknown if scleral lacerations or ruptures could be associated with primary blast effects, however, and more detailed information is required to discern actual injury mechanisms. Nevertheless, the impact of exploding fragments and debris causing secondary blast injuries to the eye is the most common blast-related injury mechanism [14]. The 37 corneal burns and 11 facial burns illustrated in Table 4 represent the only quaternary blast injuries in the analysis.

The most common blast-related head injury in this analysis was TBI, which accounted for seven out of every ten SM subjects in this case series. Of particular clinical significance to SMs and Veterans is mild TBI (mTBI), which the DoD and the Veterans Administration have defined as a concussion with loss of consciousness of 30 minutes or less. Based on this definition, AIS codes 161001.1 (mild cerebral concussion with no loss of consciousness) and 161004.2 (cerebral concussion with loss of consciousness ≤ 30 minutes) constitute mTBI in our dataset. Of the 5,629 SMs sustaining blast-related TBI, 1,731 (31%) sustained a TBI as identified by one of the above AIS codes, thus having sustained mTBI, according to this definition. By itself, mTBI is usually not severe enough to require admission to any role 3 or higher MTF unless accompanied by other traumatic injury; this number may well be an underestimate of true mTBI incidence among SMs deployed to OEF, OIF, or OND. To examine this possible gap, the DoD has tasked the Defense Centers of Excellence for Psychological Health and Traumatic Brain Injury to conduct active inquiries and report on potentially concussive events and their relationship to mTBI.

Facial penetrating injury (not further specified) and maxillary fracture were the third and ninth most common AIS-coded injury, respectively, in this analysis. These results emphasize the difficulty of protecting the facial region while maintaining situational awareness, agility, and reasonable comfort [16]. Therefore, a tradeoff exists between the level of protective coverage provided and the field of view afforded by the maxillofacial shield (MFS) [16,17]. It is also unknown which particular face protection was used by these SMs.

The MFS may be more appropriate for those SMs in combat roles who were at greater risk for facial injuries (e.g. turret gunners) than for others. This tradeoff between competing objectives-to maximize personal injury protection while maintaining optical communication, situational awareness, and agility-is a challenge to military PPE use, driving current and ongoing MOMRP research into PPE development and improvement. Similarly, combat ear plugs block combat noise while allowing the SMs to hear verbal communications, and low usage may be associated with the incidence of tympanic membrane rupture seen in this analysis, as well as other studies [10,18,19]. Personal comfort, as well as convenience and positive appearance, are further challenges to effective PPE use, should the PPE be perceived to detract from these needs. SMs may be reluctant to wear MCEP due to fogging of visual field, restriction of visual field, discomfort, and inconvenience on the battlefield [20].

Early on, the social stigma attached to wearing MCEP was that it detracted from a personal appearance and was the most challenging issue to effective use [21]. In efforts to counter this reality and to promote MCEP use, more stylish eyewear was devised in both prescription and nonprescription applications for the goggles and spectacles commercially available on the Authorized Protective Eyewear List (APEL).

Because the AIS is an anatomically based injury severity scoring system, it does not take into account the physiological effects of injury on body system functions. While an evaluation of how blast-related head and facial injury severity affected functionality would have been useful for measuring central nervous system impairment, audiometric tests measuring hearing thresholds shifts may suffice [22], as well as post injury eye examinations and oculomotor assessments. However, these were not available in the DoDTR data. Ideally, such measurements would be made longitudinally in order to determine the long-term outcomes of these injuries; currently, a knowledge that gap exists that several DoD researchers have identified [16,17,18].

The most significant limitation in this analysis was the inability to have access to data on PPE reportedly in use at the time of injury. This reduced the ability to evaluate PPE use compliance among the case population, as well as the effectiveness of PPE on injury outcomes in accordance with the original RFI. It is suggested that improved MCEP use will lead to fewer eye injuries and a reduction in eye injury severity [16]. MCEP use helps protect the eyes from secondary blast injury, but may be associated with orbital and/or maxillary fractures as the protective eyewear may deflect projectile fragments and debris away from the eyes and onto the rest of the face [16]. There is also the possibility that the blast forces may cause the eyewear to impact the eyes. While this case series included a subgroup of SMs who had sustained an orbital or maxillary fracture without an eye injury (or the possibility of debris or blast-wave effect on these types of injuries), it is not possible to determine whether MCEP use was the cause of this injury without data on PPE use [16,17].

We are cognizant of the technical demands on the battlefield. Ergonomic improvements to PPE, combined with ongoing Soldier education and enforcement, are necessary to promote PPE use. An increase in proper PPE use should improve personal injury protection on the battlefield environment [20]. Evaluation of the primary blast protection provided by goggles and spectacles on the APEL suggests that goggles provide an average of 31% better protection from primary-blast peak pressures than spectacles [16]. However, neither form of eyewear significantly reduced the amount of blast energy reaching the eyes. The balance that exists between personal injury protection and SMs' requirements to operate effectively in the battlefield is difficult to define [17].

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