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TITLE: Assessing the Effects of Concomitant Traumatic Brain Injury and Vision Loss on Wounded Warriors in Patients from Walter Reed National Military Medical Center

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14. ABSTRACT Due to the highly visual nature of military activities, eyes are frequently exposed to potential injury in military training and combat scenarios. Even the partial loss of vision in one eye could result in the medical retirement of service members. Given the highly organized structure of the eye, there is no capability to restore function to damaged retinal or optic nerve tissue. Eye injuries constitute approximately 13% of military casualties from Iraqi and Enduring Freedom and are a frequent source of non-combat and training injury. Additionally, traumatic brain injury (TBI) is frequently associated with injuries that involve the eye. This study has four specific aims: The first is to query the Walter Reed Ocular Trauma Database (WROTD), a large dataset consisting of granular data in the DoD, for military eye injuries to report on trends and outcomes related to combat ocular trauma and address capability gaps as well as determine the impact of eye trauma on the military. The second aim is to longitudinally evaluate, in a prospective ongoing protocol, the quality of life of a cohort of patients with combat ocular injuries. Measuring the quality of life impact on a prospective eye injury cohort is invaluable in evaluating non-visual quality of life measures. Despite achieving good visual acuity outcomes, some patients continue to experience significant quality of life effects following eye injuries. The third and fourth aims, also a part of the ongoing prospective protocol, will address the TBI-related visual dysfunction cohort within the prospective study. This study will continue work on aggregating the quality of life and quality of vision data, as well as, report on the visual dysfunction associated with traumatic brain injury and the impact of eye injuries on traumatic brain injury patients.					
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1. INTRODUCTION:

Considering the proportionate surface area of the eye, eye injuries constituted an excessively high percentage of military casualties from Operations Iraqi and Enduring Freedom. In addition, non-combat and training injuries resulted in over 200,000 visits between 1996-2005.^{1,2} The escalated use of asymmetric munitions resulted in a higher incidence of blast trauma, leading to an increase in cases of traumatic brain injury (TBI).³ This study had four specific aims to capture and explore combat ocular trauma data and quality of life post-injury. The first was to query the Walter Reed Ocular Trauma Database (WROTD), a large dataset consisting of granular data in the Department of Defense (DoD) of military eye injuries, to report on trends and outcomes related to combat ocular trauma. Using the trends or pattern of injuries generated by WROTD analysis, the study identified and addressed capability gaps affecting eye trauma in the military. The second aim was to evaluate prospectively the quality of life, over time, of a cohort of patients with combat ocular injuries. Service members with ocular blast injuries reported the quality of life and impact of vision loss as related to their injury. Despite achieving good visual acuity outcomes, some patients continued to experience significant quality of life effects following eye injuries. The third and fourth aims prospectively assessed TBI-related visual dysfunction. This study aggregated the quality of life and quality of vision data, as well as, reported on the visual dysfunction associated with traumatic brain injury and the impact of eye injuries on traumatic brain injury patients.

2. KEYWORDS:

combat ocular trauma, traumatic brain injury, blast injury, quality of life

3. ACCOMPLISHMENTS:

What were the major goals of the project?

Below is a summary of the major goals of the project as stated in the SOW:

1. Retrospective study “Combat ocular trauma at WRAMC: 2001-2011” (*Protocol 368537*)

- Analysis using the WROTD to identify injury patterns that are most associated with vision loss.
- Assessment of the impact of injury subtype, gender, age, and associated systemic injury on visual outcome.
- Review and validate or invalidate current Clinical and Rehabilitative Medicine capability gaps based on WROTD
- Disseminate results

2. Prospective study “Long-term visual prognosis for patients with ocular blast injuries:

DoD-VA prospective combat ocular trauma tracking program”(*Protocol 20263*)

- Complete questionnaires and update ocular health status for all study participants
- Collaborate with Defense and Veterans Brain Injury Center to assess TBI-related visual dysfunction and TBI-rehabilitation challenges in an eye injury patient population.
- Disseminate results

What was accomplished under these goals?

In total, 45 knowledge products were generated as a result of this award. This includes 14 peer reviewed published manuscripts, 2 manuscripts under peer review, 3 invited guest editorials, 11 podium presentations, 15 poster presentations. In total, these efforts provided the most robust summary of ophthalmic injuries sustained by US Service members during combat operations from 2001 to date.

As part of the study protocol entitled “Combat Ocular Trauma at Walter Reed Army Medical Center (WRAMC): 2001-2011 (IRB #368537)”, the WROTD was reviewed and queried, to update the epidemiology of combat ocular injuries in U.S. military service members during OIF and OEF from 2001-2011. The WROTD included 890 globe or adnexal combat injuries, or both, sustained by 652 United States military service members treated at WRAMC between 2001-2011.

In the paper by Harvey et al (2020) (Appendix 1), investigators presented an overview of the epidemiology of combat ocular injuries during OIF and OEF from 2001-2011 (Table 1). The primary outcomes measures were best-corrected visual acuity; ocular trauma score (OTS); globe, oculoplastic, neuro-ophthalmic, and associated non-ocular injuries; ophthalmic surgeries performed; late term complications. Bayesian Network Analysis was completed to better understand the relationships between different ocular demographic variables, injuries, surgeries, OTS and visual outcomes. The study found the primary mechanism of injury was improvised explosive device (62.47%).

Table 1. Combat Ocular Trauma

Age (yrs)	Mean, 27.2 (range, 18-53)
Gender	862 (96.85%) male/28 (3.15%) female
Documented eye protection	243 (27.30%)
Documented without eye protection	223 (25.06%)
Unknown use of eye protection	424 (47.64%)
Mechanism of injury	
Improvised explosive device (IED)	556 (62.47%)
Rocket-propelled grenade (RPG)	103 (11.57%)
Motor vehicle accident	42 (4.72%)

Gunshot wound	70 (7.87%)
Mine	27 (3.03%)
Mortar	32 (3.60%)
Helicopter crash	5 (0.56%)
Grenade	28 (3.15%)
Tank fire	2 (0.25%)
Other	24 (2.70%)
Unknown	1 (0.11%)
Unilateral	412 (46.29%)
Bilateral	478 (53.71%)
Globe/globe injury	332 (37.30%)
Globe/adnexa	80 (8.99%)
Adnexa/adnexa	34 (3.82%)
Neuro/neuro	22 (2.47%)
Globe/neuro	10 (1.12%)

Of the affected eyes, 26.6% were found to have OTS grades 1-2 (0-65), 47.6% had OTS grades 3-5 (66-100), 9.3% had adnexal injuries, and 5.3% had neuro-ophthalmic injuries (lower OTS grades associated with a worse prognosis). Visual acuity grades are presented in Table 2. The majority of patients (62.0%) had final visual acuity (VA) grades of 1-2 (20/15 – 20/200), while 29.9% of patients had final VA grades of 3-5 (less than 20/200; considered legally blind), and 8.1% had unknown final VA grades.

Table 2: Visual Acuity Grades

VA ^a	VA ^a Grade	Initial VA ^a Grade (number of eyes)	Final VA ^a Grade (number of eyes)
No Light Perception	Grade 5	140 (15.73%)	162 (18.20%)
Light Perception Hand Motion	Grade 4	165 (18.54%)	59 (6.63%)

Count Fingers 20/800 20/400	Grade 3	64 (7.19%)	45 (5.06%)
20/200 20/100 20/80 20/70 20/60 20/50	Grade 2	94 (10.56%)	59 (6.63%)
20/40 20/30 20/25 20/20 20/15	Grade 1	328 (36.85%)	493 (55.39%)
Unknown	Unknown	99 (11.12%)	72 (8.09%)

^aVisual acuity

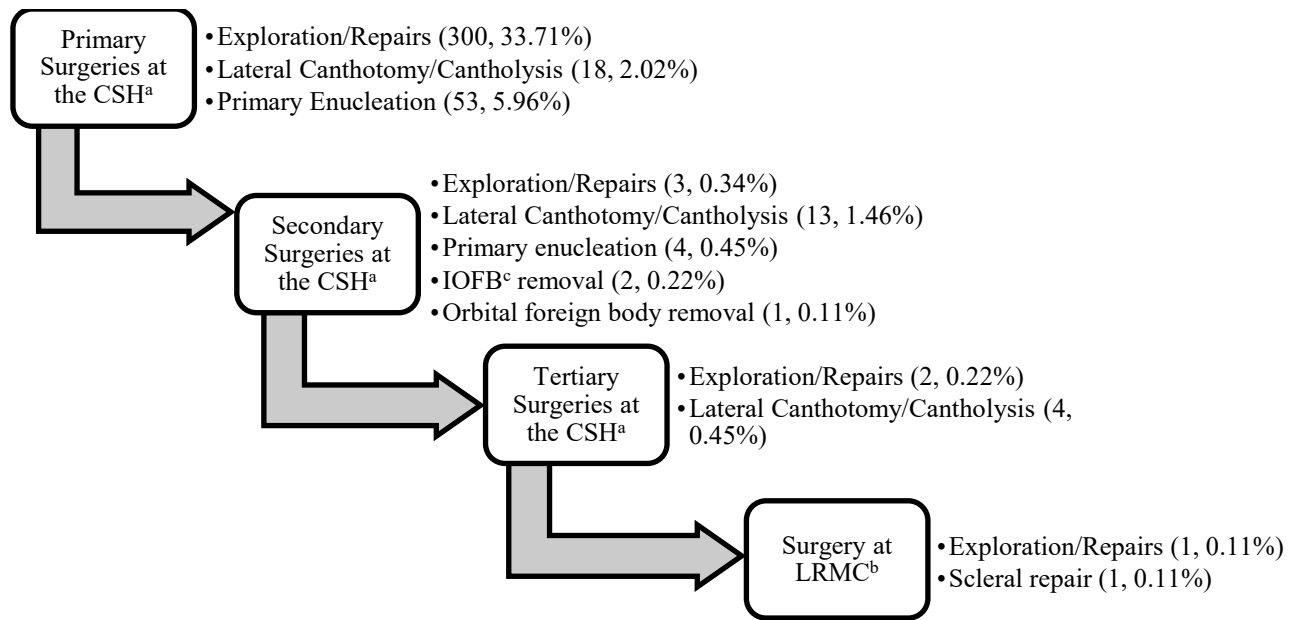
Modern day combat trauma resulted in complicated ocular injuries causing 30% of patients to be left legally blind in their injured eye. Surgical interventions are presented in Table 3. Bayesian Network Analysis revealed that the injury variables of retina (47.9%), lens (44.6%), posterior segment (43.7%) and anterior segment (40.3%), and the surgical variables of enucleation (97.6%) and cataract extraction and posterior capsule intraocular lens placement (43.3%) all had probabilities greater than 40%, while all other variables were less than 40%. Retina, posterior segment and lens injuries were most strongly associated with a poor visual prognosis. This emphasizes the importance of having a wide variety of deployable, specialty- trained ophthalmologists to ensure the best visual outcomes for wounded warriors and to maintain mission readiness (Figure 1)

Table 3: Surgeries

PPV ^a	197 (22.13%)
SB ^b	23 (2.58%)
PPL ^c	119 (13.37%)

CEPCIOL ^d	67 (7.53%)
IOFB ^e removal	118 (13.26%)
Enucleation	109 (12.25%)
Fracture repair	45 (5.06%)
PKP ^f	33 (3.71%)
Tube shunt placement	8 (0.90%)
Ptosis surgery	7 (0.79%)
Lid reconstruction	49 (5.51%)
Nasolacrimal system repair	7 (0.79%)
Strabismus surgery	14 (1.57%)
Primary surgeries	
Exploration/repair	300 (33.71%)
Lateral canthotomy and cantholysis	18 (2.02%)
Primary enucleation	53 (5.96%)
Secondary surgeries	
Exploration/repair	3 (0.34%)
Lateral canthotomy and cantholysis	13 (1.46%)
Primary enucleation	4 (0.45%)
IOFB ^e removal	2 (0.22%)
Orbital foreign body removal	1 (0.11%)
Tertiary surgeries	
Exploration/repair	2 (0.22%)
Lateral canthotomy and cantholysis	4 (0.45%)
Quaternary surgeries	
Exploration/repair	1 (0.11%)
Scleral repair	1 (0.11%)
^a Pars plana vitrectomy	
^b Scleral buckling	
^c Pars plana lensectomy	
^d Cataract extraction with posterior intraocular lens implantation	
^e Intraocular foreign body	
^f Penetrating keratoplasty	

Figure 1: Surgeries performed in a Combat Support Hospital or at Landstuhl Regional Medical Center



^aCombat Support Hospital

^bLandstuhl Regional Medical Center

^cIntraocular foreign body

The following are major findings and accomplishments yielding from injury- or condition-specific queries and analyses of the WROTD:

Poor visual acuity. In a paper by Vlasov et al (Appendix 2), the investigators aimed to identify the primary reason for poor visual acuity (worse than 20/200) among military service members with combat ocular trauma from OIF/OEF. Based on their study, they found that the incidence of ocular injuries among U.S. OIF and OEF service members evacuated from the theater of operations to WRAMC from 2001 through 2011 was high with close to a third of service members becoming legally blind. Open globe Zone III injuries (81.6%) were the number one cause of blindness. Those who sustained open globe zone III injuries were 13 times more likely

to become blind. Most injuries were caused by improvised explosive devices (64.2%).

Enucleation was the most common surgery performed (40.6%) and therefore the leading cause of blindness, followed by a multifactorial cause and direct traumatic optic neuropathy.

Corneal and corneoscleral injuries. When Vlasov et al (Appendix 3) examined the incidence and etiology corneal and corneoscleral injuries in COT from OIF/OEF, they found that corneal or corneoscleral injuries were not the only etiology for poor vision. Rather, the majority of those who had visual acuity worse than 20/200 suffered from injuries to the cornea and retina (58%). Corneal injuries accounted for 19% of all injuries sustained and most of the corneal and corneoscleral injuries were due to intraocular foreign bodies (48%), followed by penetrating (19.6%) and perforating (16.3%) injuries.

Open-globe injury. Harris et al (Appendix 4), meanwhile, reviewed the WROTD to determine the rate and type of open-globe injuries sustained during OIF/OEF. Open-globe injuries were classified by type of wound: corneal, corneo-scleral or scleral, or type of open-globe injury: perforating, rupture, penetrating or intraocular foreign body. The study found 285 (32.0%) open-globe injuries in 890 eyes in the WROTD. There were 127 (44.6%) eyes with corneal wounds, 78 (27.4%) with corneo-scleral wounds and 129 (45.3%) with scleral wounds. Injuries involving both the cornea and sclera were associated with poorer visual outcome (best corrected visual acuity of <20/200) compared to those with injuries to either the cornea or sclera alone ($p=0.038$). The type of wound was not found to be predictive of enucleation in multivariate analysis, but rather the type of open-globe injury was predictive. Perforating and globe rupture injuries were more likely to undergo enucleation.

Intraocular foreign bodies. The incidence rate of intraocular foreign bodies (IOFB) in patients during OIF/OEF was previously reported to range between 14.6% and 16.4% (Weichel et al [2008]; Thach et al [2008]).⁴⁻⁵ Justin et al's (Appendix 5) review of the WROTD found that IOFB was present in 166 of 890 (18.6%) ocular injuries (149 of 652 patients). While IOFB was common and significantly associated with more severe injuries, a multi-variate analysis did not demonstrate that IOFB alone was a predictor of final visual acuity of <20/200 when other injury features were known.

Hyphema. Hyphema is a notable presentation in combat ocular injuries. Miller et al (Appendix 6) found the incidence of traumatic hyphema is 18.9% of 890 ocular injuries in the WROTD. Improvised explosive device blasts were the most common mechanism for traumatic hyphema, leading to predominantly open hyphema (61.9%) secondary to foreign bodies. Complications significantly associated with hyphema include developing a cataract, retinal detachment, or angle recession. Additionally, the odds of having an OTS grade of 1 or 2 with worse than 20/200 final VA were significantly higher in eyes with hyphema. In eyes with open-globe hyphema, the odds were significantly higher for developing a cataract and retinal detachment and were associated with a worse OTS and final VA. The high complication rates associated with traumatic hyphema presented the importance of following patients for complications, especially cataract formation, glaucoma, anterior angle recession, and re-bleeding.

Posterior segment injury. The incidence of combat-related posterior segment injuries is high. Wold et al (Appendix 7) characterized the nature of posterior segment injuries and found that these occurred in about 50% of eyes in the WROTD and were largely due to exposure to

improvised explosive devices. Of those with posterior segment injuries, approximately 50% had a final visual acuity less than 20/200. Open globe, and Zone II and III injuries more commonly resulted in a poor final visual outcome.

Retinal detachment. Purt et al (pending peer review) examined retinal detachment associated with combat ocular trauma during OIF and OEF and the anatomic outcome and predictors of final retinal attachment status. Investigators found that 143 (16.1%) eyes had developed traumatic retinal detachment out of 890 eyes in the WROTD. Fifty eyes were enucleated due to severity of injuries while 18 eyes were not repaired. Final anatomic retinal attachment status was available for 70 eyes of which 24 eyes were not able to be surgically reattached and 46 were reattached. Based on these results, the factors that significantly increased the odds of failure to reattach the retina include macula-off status, open-globe injury, proliferative vitreoretinopathy (PVR) post-operatively, and presence of hyphema.

Proliferative vitreoretinopathy. Blackford et al (Appendix 8) assessed the risk factors associated with developing proliferative vitreoretinopathy (PVR) from combat ocular injuries in U.S. service members and the rate of final visual acuity worse than 20/200. Of the 890 eyes of 651 service members evaluated, 76 eyes (8.5%) of 66 patients developed PVR. Five patients had bilateral PVR. Nineteen patients had bilateral eye injuries. Sixty-one eyes (80.2%) had a final VA less than 20/200, finding PVR was a significant risk factor for a poor final VA ($p<0.001$). Retinal detachment (RD) was found in 52 eyes (68.4%) of patients. In patients with a RD, IOFBs ($p<0.001$), unsuccessful repair ($p=0.002$), and macular hemorrhage ($p=0.04$) were significant risk factors for the development of PVR. Time to initial retina surgery was not found to be a risk

factor for PVR development. PVR occurs frequently in combat trauma and is a significant cause of poor final visual acuity. In patients with PVR and RD, injuries caused by an IOFB, macular hemorrhage, or unsuccessful repair were significant risk factors for the development of PVR.

Post-traumatic endophthalmitis. When reviewing endophthalmitis (Colyer 2018), Colyer found a high incidence in open globe cases, with 2-11% of penetrating injury, and higher with IOFB (4-15%). Incidence was higher when vegetative matter was involved, as high as 30%. Ten percent of patients achieved 20/400 final vision. Delaying the removal of IOFBs, in concert with early primary closure, proved to be an acceptable practice. Rates of endophthalmitis were negligible and rates of PVR were similar to other reports. There was no significant advantage of early vs delayed IOFB removal if: primary closure is performed within hours of injury, broad-spectrum antibiotics are initiated, topical and systemic fluoroquinolone agents are administered for at least 7 to 10 days, and delay vitrectomy and IOFB removal for up to 21 days. However, controversies remain: duration of prophylaxis use, administration of intravitreal antibiotics, consideration of other antibiotics as prophylaxis, and use of betadine on the surface of an open globe.

Lateral canthotomy and cantholysis. Lateral canthotomy and cantholysis (LCC) is a critical intervention in orbital compartment syndrome (OCS) commonly resulting from retrobulbar hemorrhage (RBH). COT patients sustained extensive ocular injuries and after a careful assessment, prompt intervention, such as LCC, was performed to decompress orbital pressure and prevent irreversible blindness. In a study done by Jaksha et al (Appendix 9), they identified 36 eyes having undergone an LCC out of 890 eyes in the WROTD (4.04%). Although 15 of the

36 eyes (47%) had improved vision from initial to final assessment, 18 eyes (50%) had final VA equal or worse than 20/200 due to severe injuries. Frequently, patients requiring an LCC had associated injuries, especially hyphema and vitreous hemorrhage. A large portion of patients also suffered orbital fracture.

Orbital fractures. The WROTD offers a unique analysis of orbital fractures compared to civilian reports due to inclusion of visual acuity data. A study by Justin et al (Appendix 10) found 304 (34.2%) patients with ocular trauma had an orbital fracture, a higher rate compared to the civilian maxillofacial trauma studies, likely due to selection bias of using an ophthalmic-specific database. Univariate analysis found that having an orbital fracture itself and an increasing number of walls fractured led to an increased risk of blindness, defined as visual acuity less than 20/200 ($p < 0.001$). The inference being it is unlikely that orbital fractures themselves are resulting in blindness but rather associated injuries such as retinal detachment, phthisis, globe rupture or perforation and optic nerve injury. The reported rate of orbital fracture repair in this study was lower than civilian reports likely due to factors associated with evacuation from the combat theatre and other interventions delaying or canceling oculoplastic intervention. Considering an ocular trauma rate of nearly 15% with a third having an orbital fracture, approximately 2% of U.S. soldiers returning from OIF/OEF will be blinded in an injury associated with an orbital fracture.

Enucleation and evisceration. Enucleation and evisceration have lifelong impacts on patients given the combined cosmetic change and loss of vision, a plight that can be debilitating for the patient and family. The study by Stevens et al (Appendix 11) reported that 104 enucleations and

5 eviscerations were performed on 890 eyes in the WROTD (12.24%). One patient underwent bilateral enucleations and another bilateral eviscerations. Of the 109 surgical procedures, 57 (52.29%) were unilateral injuries, while 40 (36.70%) were bilateral globe-globe injuries, and 12 (11.01%) were bilateral globe-adnexal injuries. In civilian trauma, slow speed projectiles, blunt injury or a single foreign body fragment is the cause for enucleation, while in combat, enucleation was performed primarily as a result of a blast injury. The five reported primary eviscerations in this study were done in isolation by a few ophthalmologists who felt that the cosmetic outcome and mobility were better following evisceration given the lower threat of sympathetic ophthalmia, justifying the use of evisceration instead of enucleation. As clinically stable patients follow up with an ocularist for prosthetic fittings, limited data was available in the WROTD on the long term-effects of enucleation and evisceration in veterans.

Neuro-ophthalmic injuries. The prevalence of blasts in today's wars cause severe ocular injuries, often including neurologic injury. These neurologic injuries frequently include neuro-ophthalmic injuries (NOI) and traumatic brain injury (TBI). Jaksha et al (Appendix 12) reported on the incidence of NOI and associated systemic neurologic injury and TBI in combat ocular trauma; analyzed various NOI and their association with systemic neurologic injury and TBI; and completed a multivariate analysis to study whether NOI or TBI were risk factors for poor final VA. Following eye trauma in OIF and OEF, 34.54% were open globe injuries, 13.09% were optic nerve injuries, and the most common mechanism of injury was an IED blast (62.59%). Of eyes in the WROTD with systemic neurologic injury (n=229), there was a statistically significant relationship (OR 29.8, 95% CI 19.2-47.8, $p<0.001$) with neuro-ophthalmic injury. Logistic regression (per eye) found that TBI was not an independent risk factor for final visual acuity less

than 20/200 ($p=0.6$), when associated injuries that are known risk factors for blindness such as retinal detachment, phthisis, globe rupture or perforation and optic nerve injury, are also included in the model (all $p<0.001$). Service members with NOI must undertake hundreds of hours of neuro-ophthalmic rehabilitation in addition to recovery from other combat injuries. NOI occurs 20% of the time in combat and is very strongly associated with systemic neurologic injury and TBI, particularly cranial nerve and optic nerve injuries. Direct optic nerve injury, but not TBI, was a risk factor for a poor final visual acuity.

Traumatic brain injury. A review by Justin et al (2018) of the incidence of TBI in the WROTD examined the number of patients with TBI and final VA, finding approximately 35% of patients with a TBI had a final visual acuity less than 20/200. TBI was associated with optic nerve injury and cranial nerve injury. Although optic nerve injuries have been found to be a risk factor for final visual acuity less than 20/200, TBI itself was not. There is a paucity of research connecting neuro-ophthalmic injuries and TBI. In addition, previous studies have documented vague visual deficits in patients with TBI, but very few have documented the actual visual acuities. Additional research is needed to observe TBI without associated ocular injury or visual complaints because results from this study included individuals with TBI and ocular trauma.

As part of the study protocol entitled “Long term visual prognosis for patients with ocular blast injuries: DoD-VA prospective combat ocular trauma tracking program (IRB# 20263),” the investigators longitudinally assessed self-reported quality of life of U.S. military service members after combat ocular trauma.

An early report on the prospective observational study of service members sustaining ocular trauma described the visual outlook and quality of life of 137 service members after combat ocular trauma. This study provided evidence that combat ocular trauma is associated with a lower visual quality of life, albeit limitations included the smaller sample size and the limited documentation of the use of eye protection at time of injury among participants (Appendix 13).

In a single-center, prospective observational study, Sia et al (Appendix 14) assessed visual and health-related quality of life (QOL) among U.S. military service members who sustained COT with or without associated TBI and were evacuated to WRAMC and subsequently the Walter Reed National Military Medical Center. Eighty-eight (88) participants completed the National Eye Institute Visual Function Questionnaire (VFQ- 25) at enrollment and at follow-up (>1 year) and supplemental surveys: Neurobehavioral Symptom Inventory (NSI), the Medical Outcomes 36-item Short Form Survey (SF-36) and Mayo-Portland Adaptability Inventory (MPAI).

Similar to the findings in WROTD retrospective studies, blast mechanisms accounted for approximately 70% of the injuries. A vast majority (88.6%) of the participants had associated TBI. When assessed for vision-related QOL, results of the study showed significant overall improvement at follow up and in aspects particularly related to near activities and peripheral vision. Meanwhile, those with associated TBI history seemed to experience greater degree of neurobehavioral symptoms and functional limitations as well as less favorable health state compared to those without TBI history. The results of regression analyses suggest visual acuity of the worse eye, age at the time of injury and TBI status are important factors that could have an impact upon the QOL in patients with COT in the long term. The findings of the study suggested that vision-related QOL of COT patients is generally good in the long term however those with

both COT and a history of TBI can have significantly worse functioning in several domains compared to those without TBI. As TBI is a common finding in COT, this association is an important factor impacting this population's overall clinical presentation and daily functions.

What opportunities for training and professional development has the project provided?

- This project offered medical students and ophthalmology residents options for training and professional development. Twenty-four (24) students and residents were mentored to learn about institutional review board requirements; develop skills to navigate the research process including creating hypotheses and study aims, literature review, data collection, data analysis, interpreting results or findings, preparing presentations for conferences, and manuscript development for publication. Results of the process are presented in the *PRODUCTS* section of this report.
- The prospective nature of the Combat Ocular Trauma study called for medical student and resident participation in active research and data collection developing research skills and interest.
- Despite an interest in ocular trauma worldwide, this study found appropriate venues (i.e. meetings or scientific journals with related topics) for publishing ocular trauma studies limited. Experiencing the paucity of appropriate venues led to investigators on the study's increased participation in forums as panelists and presenters.
- The PI and Dr. Justin, an AI, helped establish the American Society of Ophthalmic Trauma (ASOT). They are both on the executive committee. The first virtual meeting took place in June 2020 and a second meeting was held June 2021. Through work on the

ASOT, investigators on this study, in coordination with the ophthalmology community, are working on standardization of ophthalmic trauma proficiency and system of care.

How were the results disseminated to communities of interest?

Results of this research effort, as evidenced in the *PRODUCTS* section of this report varied in mode of dissemination: research competitions/symposia, invited lectures at different institutions and Ophthalmology conferences with an international audience, published results in peer reviewed journals, editorials, study and publications mentioned in the Walter Reed Military Medical Center Research monthly newsletter, and principal and associate investigators participating as panelists at numerous conferences.

What do you plan to do during the next reporting period to accomplish the goals?
Nothing to Report.

4. IMPACT:

What was the impact on the development of the principal discipline(s) of the project?

- The closing of some of the knowledge gaps, as a result of this study, has informed the ophthalmic community of urgent trauma issues that should be considered when establishing military knowledge, skills and ability guidelines as well as pre-deployment ophthalmologist refresher training recommendations.

- *Inadequate epidemiology, mitigation, and treatment of military-relevant injuries and diseases incident to military service to ocular structures and the visual system.*

Knowledge products generated by this study provide epidemiological support incident to combat ocular trauma and traumatic brain injury with ocular trauma.

- *Inadequate vision restoration and regeneration*

Results of the knowledge products found ensuring appropriate ophthalmic support is available at earliest potential point of care to be important. Severity of posterior segment injuries in visual acuity prognosis emphasizes the need for early retinal care to ensure the best possibility for vision restoration.

- ***Inadequate protection and prevention strategies***

This study emphasized prevention to be the most effective strategy. Adaptive technology to improve ballistic eyewear to allow energy release, thereby limiting shearing damage, may minimize currently invisible damage.

- ***Lack of knowledge, capabilities, and equipment for early responders to diagnose and mitigate traumatic eye injuries and diseases in remote environments***

Efforts resulting from this study aimed to provide education and simulation technology to aid the non-ophthalmic provider in urgent treatment (ER and trauma doctors not specialized in ophthalmology). The PI and investigators are working on a multi-pronged approach to educate early responders: ASOT online modules, working with OTSL to develop a medic/ ophthalmic technician module to train on assisting in ophthalmic care, grant proposal to develop a simulator to train non-ophthalmic care providers on eye-injury management in a deployed or austere training environment.

- ***Inadequate understanding of pathophysiology of ocular trauma injuries and diseases***

Knowledge products from this study aimed to address the multiple causes of ocular trauma-related blindness, both by type of injury (i.e. lacerations,

intraocular foreign body, open or closed globe injury, TBI, etc) and by surgical intervention (i.e. intraocular foreign body removal, enucleation, canthotomy, etc) to further understanding of traumatic injuries to the eye.

- ***Inadequate vision and multi-sensory rehabilitation strategies and quality of life measures***

Assessing the impact of COT and TBI on vision and health-related quality of life in the *prospective* cohort found different blast mechanisms accounted for almost 70% of injuries. Most participants had unilateral eye involvement, with a vast majority suffering from TBI. Although 93% of the participants had relatively good visual acuity in the better eye ($\geq 20/40$), the injuries, seemed to have a measurable impact on their functional status and general well-being over time.

- ***Inadequate understanding of the epidemiology, etiology, and treatments of vision and multi-sensory dysfunction associated with traumatic brain injury (TBI)***

A yet unpublished study by Flor et al (pending peer-review) discusses sustaining injuries in environments where TBI evaluation may be overlooked or delayed due to initial life-saving interventions, especially when resources are limited.

Identifying risk factors in ophthalmic trauma that may suggest TBI would aid in risk stratification for the detection of TBI in patients with COT, especially in a military environment where migration through various levels of care may make it easier to miss crucial evaluations.

- ***Inadequate vision readiness standards and assessment strategies***

The PI participates in a working group to establish knowledge, skills and ability (KSA) requirements for ophthalmologists. In addition, pre-deployment training has been ophthalmologists focusing on retraining skills relevant to incident trauma. The information from publications in this research effort will inform refinements in KSA scoring algorithms in the future potentially, as well as serve as targets for improved treatment strategies, which may require new KSA metric considerations. KSA discussions have been on hold for the past year due to COVID.

- ***Lack of ocular simulation models and tissue substitutes to replace current tissue-based training and education techniques***

The PI and associate investigators' ongoing efforts include participating in multiple efforts to develop and test ocular simulation models (Ocular trauma microsurgery simulator, Ocular and craniofacial trauma treatment training system, Bioniko feasibility for corneal lacerations); develop tissue substitutes (Generation of Simulation Ophthalmic Tissues- corneal tissue with embedded sensors to track tissue manipulation and surgical motion); and develop and test drug-eluting sutures which may potentially have a role and impact on corneal wound healing, PVR formation and intraocular inflammation.

- Some of the data from this research effort was instrumental in driving development of Clinical Practice Guidelines (CPGs) for ocular trauma. Newly added CPGs include antibiotics for open globe and intraocular foreign body; lateral canthotomy, inferior cantholysis technique with instructional illustrations (Eye Trauma: Initial Care [CPG ID:03]; and Ocular Injuries and Vision-Threatening Conditions in Prolonged Field Care

[CPG ID: 66]); and aeromedical evacuation considerations (Eye Trauma: Initial Care [CPG ID:03]). Updated and published CPGs can be accessed in the Joint Trauma System website (https://jts.amedd.army.mil/index.cfm/PI_CPGs/cpgs). The Vision Center of Excellence is the primary venue for discussion of these matters, and they continue to regularly meet with the PI and AI's to discuss targets of opportunity for research and development in ophthalmic trauma, culminating in an ophthalmic research symposium in June 2021, which has the potential to redirect funds to support eye and vision research, particularly in areas that are targets of opportunity for rapid development.

- Military ophthalmologists are likely to evaluate further evacuation patterns of patients with various ophthalmic conditions to better quantify and improve outcomes.
- Drs. Colyer and Justin joined as associate investigators on a new study “Epidemiology of Combat Ocular Injury to Guide Prolonged Field Care,” which aims to develop a system to inform treatment requirement timelines in a field setting to reduce loss of visual acuity.
- Further, the PI is collaborating with investigators on trauma studies to share access to the WROTD and the prospective data set, encouraging wide use of existing data to inform of specific military-relevant injuries.
- To aid in ongoing trauma training, Dr. Colyer continues to engage with planners of the Annual Tri-Service Ocular Trauma Surgery Lab (OTSL), a course providing ocular trauma medical skills training using live and simulation models, to seek out alternatives to live tissue training. The OTSL, in addition to training residents, offers the opportunity for refresher skills training to deploying ophthalmologists. Additional training modules for optometrists, medics and ophthalmic technicians are in development. Knowledge

gained from this study helps shape trauma training in order to better prepare for future conflicts.

What was the impact on other disciplines?

TBI results from the study (Justin et al MHSRS presentation and Sia- Appendix 1) have been shared within TBI community. Additional research is needed to observe TBI without associated ocular injury or visual complaints. Current work stops short of being conclusive because results from this study did not include individuals with TBI but no ocular trauma.

Based on the awareness of existing gaps in knowledge and skill acquisition related to ophthalmic trauma, Dr. Colyer submitted a collaborative grant proposing to provide anatomically accurate simulation models for use by non-specialists managing eye trauma to educate and train ophthalmic first aid. This will address gaps in Role 1 and Role 2 ophthalmic clinical and procedural skills. The simulators aim to reproduce the appearance and feel of ocular chemical injury, orbital compartment syndrome, and open globe injury.

What was the impact on technology transfer?

- Transfer of results to Vision Center of Excellence
- Transfer of results to interested DoD investigators (Defense Veterans Brain Injury Center TBI study and Epi study)
- Increased outreach to ocular trauma community: Initial difficulties publishing trauma results prompted outreach by investigators to develop communities of interest at the American Academy of Ophthalmology, OTSL, and online.

- Participating in the startup and ongoing support of American Society of Ophthalmic Trauma <https://theasot.com/> An initiative of ASOT is education. Education within the ophthalmic community as well as non-ophthalmologist community (Nurses, ED staff, Pas, EMTs).

What was the impact on society beyond science and technology?

- Investigators on this study worked to fill the aforementioned vision capability gaps and have contributed to a change in clinical practices for the epidemiology, mitigation and treatment of ocular trauma. While these capability gaps were developed by the military, impact can be extrapolated to non-military society. Furthermore, despite ocular trauma in this study being primarily blast mechanism related, there has been unfortunate exposure in society to similar injury.

5. CHANGES/PROBLEMS:

Changes in approach and reasons for change

Nothing to report

Actual or anticipated problems or delays and actions or plans to resolve them

Nothing to Report.

Changes that had a significant impact on expenditures

Nothing to Report.

Significant changes in use or care of human subjects, vertebrate animals, biohazards, and/or select agents

Nothing to Report.

Significant changes in use or care of human subjects

Not applicable.

Significant changes in use or care of vertebrate animals.

Not applicable.

Significant changes in use of biohazards and/or select agents

Not applicable.

6. PRODUCTS: List any products resulting from the project during the reporting period. If there is nothing to report under a particular item, state “Nothing to Report.”

- **Publications, conference papers, and presentations**

Report only the major publication(s) resulting from the work under this award.

Journal publications.

All publications below acknowledged federal support except Appendix 13

1. Harvey MM, Justin GA, Brooks DI, Ryan DS, Weichel ED, Colyer MH. **Ocular Trauma in Operation Iraqi Freedom and Operation Enduring Freedom from 2001 to 2011: A Bayesian Network Analysis.** Ophthalmic Epidemiol. 2021 Aug;28(4):312-321. doi: 10.1080/09286586.2020.1828494. Epub 2020 Sep 30. PMID: 32998604.
2. Vlasov A, Ryan DS, Ludlow S, Weichel ED, Colyer MH. **Causes of combat ocular trauma-related blindness from Operation Iraqi and Enduring Freedom.** J Trauma Acute Care Surg. 2015. J Trauma Acute Care Surg. 2015 Oct;79 (4 Suppl 2):S210-5.
3. Vlasov A, Ryan DS, Ludlow S, Coggin A, Weichel ED, Stutzman RD, Bower KS, Colyer MH. **Corneal and Corneoscleral Injury in Combat Ocular Trauma from Operation Iraqi Freedom and Enduring Freedom.** Mil Med 2017; 182, 3/4:114-7.
4. Harris JP, Justin GA, Brooks DI, Woreta FA, Agrawal RV, Ryan DS, Weichel ED, Colyer MH. **Open-globe wounds in operation Iraqi Freedom and Operation Enduring Freedom: risk factors for poor visual outcomes and enucleation.** Acta Ophthalmol. 2021 Feb 10. doi: 10.1111/aos.14790. Epub ahead of print. PMID: 33565256.

5. Justin GA, Baker KM, Brooks DI, Ryan DS, Weichel ED, Colyer MH. **Intraocular Foreign Bodies in Operation Iraqi freedom and Operation Enduring Freedom: 2001-2011.** *Ophthalmology*. 2018 Jul 20. pii: S0161-6420(18)30179-9. doi:10.1016/j.ophtha.2018.06.006.
6. Miller NR, Justin GA, Kim WI, Brooks DI, Ryan DS, Weichel ED, Colyer MH. **Hyphema in Open-Globe Versus Closed-Globe Injuries in Operation Iraqi Freedom and Enduring Freedom: 2001-2011.** *Mil Med*. 2020 Jun 8;185(5-6):e768-e773. doi: 10.1093/milmed/usz405.
7. Wold AM, Justin GA, Hobbs SD, Baker KM, Brady DP, Aden JK, Ryan DS, Weichel ED, Colyer MH. **Posterior Segment Injuries in Operation Iraqi Freedom and Operation Enduring Freedom: 2001-2011.** *Retina*. 2021 May 27. doi: 10.1097/IAE.0000000000003221. Epub ahead of print. PMID: 34050100.
8. Blackford BG, Justin GA, Baker KM, Brooks DI, Wang HH, Ryan DS, Weichel ED, Colyer MH. **Proliferative Vitreoretinopathy After Combat Ocular Trauma in Operation Iraqi Freedom and Operation Enduring Freedom: 2001-2011.** *Ophthalmic Surg Lasers Imaging Retina*. 2020 Oct 1;51(10):556-563. doi: 10.3928/23258160-20201005-03. PMID: 33104222.
9. Jaksha AF, Justin GA, Cleland JM, Ryan DS, Weichel ED, Colyer MH. **Lateral Canthotomy in Operation Iraqi Freedom and Operation Enduring Freedom: 2001-2011.** *Ophthalmic Plast Reconstr Surg*. 2018 Jul 3. doi: 10.1097/IOP.0000000000001168.
10. Justin GA, Turnage WA, Brooks DI, Davies BW, Ryan DS, Eiseman AS, Weichel ED, Colyer MH. **Orbital Fractures and Associated Ocular Injuries in Operation Iraqi Freedom and Operation Enduring Freedom Referred to a Tertiary Care Military**

Hospital and the Effect on Final Visual Acuity. Ophthalmic Plastic and Reconstructive

Surgery: January/February 2020 - Volume 36 - Issue 1 - p 55-60. doi:

10.1097/IOP.0000000000001461

11. Stevens BJ, Justin GA, Reed DS, Jaksha AF, Davies BW, DeMartelaere SL, Ryan DS,

Weichel ED, Colyer MH. **Enucleations and Eviscerations for Combat Ocular**

Trauma Performed During Operations Iraqi and Enduring Freedom: 2001 to 2011.

The Journal of craniofacial surgery. 2019. Published ahead of print. DOI:

10.1097/SCS.0000000000005294

12. Jaksha AF, Justin GA, Brooks DI, Elward CJ, Ryan DS, Weichel ED, Colyer MH.

Neuro-Ophthalmic Injuries With Systemic Neurologic Injury or Traumatic Brain

Injury in Operation Iraqi Freedom and Operation Enduring Freedom. J

Neuroophthalmol. 2020 Feb 27. doi: 10.1097/WNO.0000000000000913. Epub ahead of print. PMID: 32108667.

13. McLaughlin A, Colyer MH, Ryan DS, Sia RK, Weichel ED, Spiegelman A, Eaddy SG,

Mazzoli RA, Bower KS. **Self-reported Visual Quality of Life After Combat Ocular**

Trauma. Mil Med 2017; 182, 3/4:239-42.

14. Sia RK, Ryan DS, Brooks DI, Kagemann JM, Bower KS, French LM, Justin GA, Colyer

MH. **The Impact of Combat Ocular Trauma and Traumatic Brain Injury on Vision-
and Health-Related Quality of Life Among U.S. Military Casualties.** Mil Med. 2021

Jun 12:usab233. doi: 10.1093/milmed/usab233. Epub ahead of print. PMID: 34117765.

Pending peer review:

- Justin GA, Baker KM, Brooks DI, Ryan DS, Weichel ED, Colyer MH. Retinal Detachment and Surgical Outcomes in Operation Iraqi Freedom and Operation Enduring Freedom: 2001-2011. *Retina*
- Flor R, Purt Boonkit, Sia RK, Ryan DS, Kagemann JM, Powell BE, French LM, Justin GA, Colyer MH. Correlative Factors for Traumatic Brain Injury in Combat Ocular Trauma. *Milmed*.

Editorials:

- Colyer MH. **Open-globe injuries: A global issue of protection.** *Clinical and Experimental Ophthalmology*. 17 June 2019 <https://doi.org/10.1111/ceo.13562>
- Colyer MH, Mazzoli RA. **Complex ocular trauma outcomes and system capabilities: lessons from a combat zone and implications for national eye trauma care.** *Eye* (2021). <https://doi.org/10.1038/s41433-020-01319-7>
- Colyer MH. **Department of Defense and Eye Injury Data: Shedding New Light,** *Military Medicine*, Volume 185, Issue 11-12, November-December 2020, Pages 487–488, <https://doi.org/10.1093/milmed/usaa156>

Books or other non-periodical, one-time publications.
None.

Other publications, conference papers, and presentations. (*) *if presentation produced a manuscript.*

Presentation Info.	Author/Presenter	Location/Conference
Military Ocular Trauma: The U.S. Experience in Recent Global Conflict.	Colyer MH	Sally Letson Lecture Series, Ottawa, Canada. September, 2017
*Intraocular Foreign Bodies in Operation Iraqi Freedom and Operation Enduring Freedom: 2001-2011	Justin GA	American Academy of Ophthalmology Society of Military Ophthalmology Meeting November 2017

*Lateral Canthotomy and Cantholysis in Operation Iraqi Freedom and Operation Enduring Freedom: 2001-2011	Jaksha A	American Academy of Ophthalmology Society of Military Ophthalmology Meeting November 2017
Military Ocular Trauma: The U.S. Experience in Recent Global Conflict.	Colyer MH	Cincinnati Grand Rounds Lecture December 2017
*Open versus closed hyphema: lessons learned in Operations Iraqi Freedom and Enduring Freedom	Miller NR	Association for Research in Vision and Ophthalmology (ARVO) Annual Meeting May 2018
*Corneal Laceration in Operation Iraqi Freedom and Operation Enduring Freedom: 2001-2011	Justin GA	Asia-Pacific Association of Cataract and Refractive Surgeons (APACRS) Annual Meeting May 2018
*Risk factors associated with developing proliferative vitreoretinopathy (PVR) after posterior segment trauma from combat injuries in service members during OIF/OEF from data collected at Walter Reed Army Medical Center (WRAMC) from 2001-2011	Blackford BG	Military Health System Research Symposium Annual Meeting August 2018
<i>Panelist "Pointless" vision loss</i>	Colyer MH	Ocular TraumaCON 2018 held on 13-15 July 2018 at Chennai, India
Endophthalmitis in US Military	Colyer MH	Ocular TraumaCON 2018 held on 13-15 July 2018 at Chennai, India
Repair of posterior segment injuries in concert with an opacified cornea	Colyer MH	Ocular TraumaCON 2018 held on 13-15 July 2018 at Chennai, India
*Proliferative Vitreoretinopathy after Combat Ocular Trauma in Operation Iraqi Freedom and Operation Enduring Freedom: 2001-2011	Baker KM	2018 Military Health System Research Symposium (MHSRS), Kissimmee, FL
Translating Military TBI Research into Clinical Practice - Traumatic Brain Injury in Combat Ocular Trauma in Operations Iraqi and Enduring Freedom: 2001-2011	Justin GA	2018 Military Health System Research Symposium (MHSRS), Kissimmee, FL
<i>Panelist during a breakout session on Ocular Trauma</i>	Colyer MH	2018 Military Health System Research Symposium (MHSRS), Kissimmee, FL
*Open versus closed hyphema: lessons learned in Operations Iraqi Freedom and Enduring Freedom	Miller NR	Association for Research in Vision and Ophthalmology (ARVO) Annual Meeting May 2018, Oahu, HI

*Corneal Laceration in Operation Iraqi Freedom and Operation Enduring Freedom: 2001-2011	Justin GA	Asia-Pacific Association of Cataract and Refractive Surgeons (APACRS) Annual Meeting May 2018
*Neuro-ophthalmic Injuries with Concomitant Systemic Neurologic Injury or Traumatic Brain Injury in Operation Iraqi Freedom and Operation Enduring Freedom: 2001-2011	Jaksha A	American Academy of Ophthalmology 2018, Chicago, IL
*Long-term prognosis of patients with ocular blast injuries	Stoddard AR	2019 National Capital Area TBI Research Symposium, Bethesda, MD
*Posterior Segment Injuries in Operation Iraqi Freedom and Operation Enduring Freedom: 2001-2011	Justin GA	American Society of Retina Specialists (ASRS) annual meeting 2019, Chicago, IL
*Orbital Fractures in Operation Iraqi Freedom and Operation Enduring Freedom: 2001-2011	Justin GA	Association for Research in Vision and Ophthalmology (ARVO) Annual Meeting May 2019, Vancouver BC
Ocular Trauma in Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF): 2001-2011	Harvey MA	Association for Research in Vision and Ophthalmology (ARVO) Annual Meeting May 2019, Vancouver BC
Optic Nerve Avulsions with Globe Preservation	Vu	Association for Research in Vision and Ophthalmology (ARVO) Annual Meeting May 2019, Vancouver BC
*Posterior Segment Injuries in Operations Iraqi and Enduring Freedom: 2001-2011	Justin GA	37th Annual Meeting of the American Society of Retina Specialists, July 26–30, 2019, Chicago, Illinois
How to Preserve & Restore Eyesight After Combat Trauma- Ocular Trauma In Operation Iraqi Freedom (OIF) And Operation Enduring Freedom(OEF): 2001-2011	Justin GA	2019 Military Health System Research Symposium 19-22 August, Kissimmee, FL
Ocular Trauma in Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF): 2001-2011	Harvey MM	2019 Military Health System Research Symposium 19-22 August, Kissimmee, FL

Preventing Post-trauma Endophthalmitis	Colyer MH	American Academy of Ophthalmology Annual Meeting 12-15 October, San Francisco CA
<i>Panel Chair- Ophthalmic Trauma Worldwide: Advocacy, Occupational, Environmental and Warfare</i>	Justin GA	World Congress of Ocular Trauma 14-15 December 2019, New Delhi, India
Epidemiology and Practice Patterns of US Military Ophthalmologists in Iraq and Afghanistan: 2002-2018	Justin GA	World Congress of Ocular Trauma 14-15 December 2019, New Delhi, India
<i>Panel Chair- Ophthalmic Trauma Worldwide: Epidemiology & Prevention</i>	Colyer MH	World Congress of Ocular Trauma 14-15 December 2019, New Delhi, India
Educational approaches to training ophthalmologists in ocular trauma	Colyer MH	World Congress of Ocular Trauma 14-15 December 2019, New Delhi, India
Management of posterior segment injuries with opacified cornea	Colyer MH	World Congress of Ocular Trauma 14-15 December 2019, New Delhi, India
<i>1st Annual Virtual Resident Ophthalmic Trauma Competition</i>	Grant Justin: Co-Director	Virtual 20 June 2020
<i>World Ophthalmology Congress</i>	Colyer MH, Justin GA	25 June 2020
<i>International Society of Ocular Trauma XIVth meeting</i>	Colyer MH, Justin GA	8-11 October 2020
<i>American Academy of Ophthalmology Annual Meeting- Trauma Panel</i>	Colyer MH, Justin GA	14-17 November 2020

- Website(s) or other Internet site(s)**

The American Society of Ophthalmic trauma was chartered and active for the past two years

holding its first virtual symposium on 20 June 2020. www.theasot.com

- **Technologies or techniques**

Nothing to Report.

- **Inventions, patent applications, and/or licenses**

Nothing to Report.

- **Other Products**

The PI is collaborating with investigators on trauma studies to share access to the WROTD and prospective data set, encouraging wide use of existing data to inform of specific military-relevant injuries.

7. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

What individuals have worked on the project?

Personnel	Role	Percent Effort	Contribution to Project
Marcus H. Colyer	PI	5%	Dr. Colyer oversaw the work done in support of this project. He set the direction of the study and was responsible for ensuring that budget, salary and regulatory issues were managed effectively. He was responsible for all reporting requirements and all publications resulting from this project. He presented study findings at scientific meetings. He has spent over a decade compiling the WROTD to provide a foundation for analysis.
Eric Elster	Co-investigator	5%	Dr. Elster advised the PI on matters pertaining to the IRB protocol.
Louis French	Co-investigator	5%	Dr. French advised the PI on matters pertaining to the TBI.
Grant Justin	Co-investigator	5%	Dr. Justin worked with the PI to present results as well as assisting Dr. Colyer and the research staff with the development of publications, mentoring medical students and staff.
Mary Ann Sullivan	Co-investigator	5%	Dr. Sullivan worked with the PI and AIs to coordinate research efforts at NMCSO.
Denise S. Ryan	Co-investigator	20%	Ms. Ryan assisted with IRB and ORP protocol approval. She provided administrative and technical resources in order to achieve the program goals. She assisted with data collection,

Rose K. Sia	Co-investigator	10%	preparation of scientific reports and manuscripts in collaboration with other study team members. Dr. Sia managed IRB and ORP protocol approval. She assisted with data collection, preparation of scientific reports and manuscripts, mentorship in collaboration with other study team members.
Dan Brooks	Statistician	20%	Dr. Brooks assisted in reviewing and organizing data and subsets, data analysis and preparation of data for presentation.
Janice Kagemann	Research Associate	100%	Ms. Kagemann worked with Dr. Colyer to consent and re-consent prospective study participants, aggregate data, and be an administrative resource to achieve program goals. She contributed to preparation of data, publications, clearances and research reports.

Has there been a change in the active other support of the PD/PI(s) or senior/key personnel since the last reporting period?

Ms. Kagemann is no longer employed due to grant funding ending.

What other organizations were involved as partners?

1. Organization Name: Brooke Army Medical Center

Location of Organization: Fort Sam Houston, TX

Partner's contribution to the project: Collaboration

2. Organization Name: Navy Medical Center San Diego

Location of Organization: San Diego, CA

Partner's contribution to the project: Collaboration

8. SPECIAL REPORTING REQUIREMENTS

Assessing the Effects of Concomitant Traumatic Brain Injury and Vision Loss on Wounded Warriors In Patients from Walter Reed National Military Medical Center
Log number: BA 150344, Award # W81XWH-17-2-0007



PI: Marcus H. Colyer

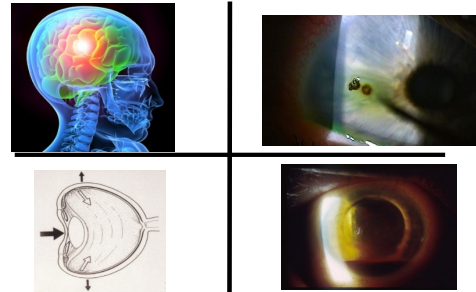
Org: Uniformed Services University of the Health Sciences

Award Amount: \$492,162.00

Study/Product Aim(s)

1. Perform analysis on Walter Reed Ocular Trauma Database (WROTD) in order to report the scope/ severity of eye injuries and the effects of eye trauma on the military.
2. Longitudinally evaluate the quality of life of a cohort with ocular blast injuries.
3. In collaboration with the Defense and Veterans Brain Injury Center, we will longitudinally follow and determine TBI-related visual dysfunction on a cohort with ocular blast injuries.
4. Assess and report on visual dysfunction associated with TBI as well as the impact of eye injuries on TBI patients.

Due to the highly visual nature of military activities, eyes are frequently exposed to potential injury. There is currently limited information regarding the frequency, impact, and outcomes related to military eye injuries. Furthermore, we hypothesize that eye injuries complicate recovery from traumatic brain injury. Exploring WROTD, we plan to explore outcomes, trend or pattern of injuries that may help identify and address capability gaps as well as determine the impact of eye trauma on the military. Additionally we will explore why, despite achieving good visual acuity outcomes, some patients continue to experience significant changes in the quality of life following eye injuries.



Accomplishment: Reporting on capability gaps continues in the effort to study ocular trauma and TBI-related visual dysfunction.

Timeline and Cost

Activities	17	18	19	20	21
Analyze and publish Walter Reed Ocular Trauma Dataset					
Measure and report visual quality of life indicators for eye injured patients					
Collaborate with DVBIC, assess TBI-related visual dysfunction and TBI rehabilitation challenges in eye injured cohort					
Estimated Total Budget (\$492.1K)	32	118	129.3	159.3	50.3

Updated: August 18, 2021

Goals/Milestones

- CY17 Goal** – Regulatory approval and identification of capability gaps
- ☑ Ensure continued IRB approval of existing protocols
 - ☑ Modify existing protocols to align with study objectives
 - ☑ Obtain HRPO approvals
 - ☑ Review WROTD and identify publication priorities
- CY18 Goals** – Coordination of blast injury and TBI related dysfunction
- ☑ Use data published from study to inform KSAs and Ocular Trauma Surg. Lab
 - ☑ Report on capability gaps
 - ☑ Resume data collection for quality of life cohort
- CY19 Goal** – Reporting on WROTD and TBI
- ☑ Report on capability gaps
 - ☑ Identify eyes in the prospective study with TBI and ocular blast injury
- CY20 Goal** – Reporting on WROTD and TBI
- ☑ Ongoing data collection, analysis, reporting and publication drafting
 - ☑ Report on visual dysfunction after blast injury (submitted for review)
- CY21 Goal** – Final reporting and publication submissions
- ☑ Finalize manuscripts and reports
- Actual Expenditure:** \$488,914.10

9. REFERENCES:

1. Hilber D, Mitchener T, Stout J et al. Eye Injury Surveillance in the U.S.
Department of Defense, 1996-2005, American Journal of Preventative Medicine, 36, S78-85.
2. Mader TH, Carroll RD, Slade CS et al. Ocular War Injuries of the Iraqi Insurgency, January-September 2004, Ophthalmology, 2006 113, 997-104.
3. Sia RK, Ryan DS, Brooks DI, Kagemann JM, Bower KS, French LM, Justin GA, Colyer MH. The Impact of Combat Ocular Trauma and Traumatic Brain Injury on Vision- and Health-Related Quality of Life Among U.S. Military Casualties. Mil

Med. 2021 Jun 12;usab233. doi: 10.1093/milmed/usab233. Epub ahead of print.
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5. Thach AB, Johnson AJ, Carroll RB, et al. Severe eye injuries in the war in Iraq, 2003e2005. *Ophthalmology*. 2008;115: 377e382.

10. APPENDICES:

Appendix 1. Ocular Trauma in Operation Iraqi Freedom and Operation Enduring Freedom from 2001 to 2011: A Bayesian Network Analysis.

Appendix 2. Causes of combat ocular trauma-related blindness from Operation Iraqi and Enduring Freedom.

Appendix 3. Corneal and Corneoscleral Injury in Combat Ocular Trauma from Operation Iraqi Freedom and Enduring Freedom.

Appendix 4. Open-globe wounds in operation Iraqi Freedom and Operation Enduring Freedom: risk factors for poor visual outcomes and enucleation.

Appendix 5. Intraocular Foreign Bodies in Operation Iraqi freedom and Operation Enduring Freedom: 2001-2011.

Appendix 6. Hyphema in Open-Globe Versus Closed-Globe Injuries in Operation Iraqi Freedom and Enduring Freedom: 2001-2011.

Appendix 7. Posterior Segment Injuries in Operation Iraqi Freedom and Operation Enduring Freedom: 2001-2011.

Appendix 8. Proliferative Vitreoretinopathy After Combat Ocular Trauma in Operation Iraqi Freedom and Operation Enduring Freedom: 2001-2011.

Appendix 9. Lateral Canthotomy in Operation Iraqi Freedom and Operation Enduring Freedom: 2001-2011.

Appendix 10. Orbital Fractures and Associated Ocular Injuries in Operation Iraqi Freedom and Operation Enduring Freedom Referred to a Tertiary Care Military Hospital and the Effect on Final Visual Acuity.

Appendix 11. Enucleations and Eviscerations for Combat Ocular Trauma Performed During Operations Iraqi and Enduring Freedom: 2001 to 2011.

Appendix 12. Neuro-Ophthalmic Injuries With Systemic Neurologic Injury or Traumatic Brain Injury in Operation Iraqi Freedom and Operation Enduring Freedom. J Neuroophthalmol. 2020 Feb 27. doi: 10.1097/WNO.0000000000000913. Epub ahead of print. PMID: 32108667.

Appendix 13. Self-reported Visual Quality of Life After Combat Ocular Trauma.

Appendix 14. The Impact of Combat Ocular Trauma and Traumatic Brain Injury on Vision- and Health-Related Quality of Life Among U.S. Military Casualties

Appendix 15. Open-globe injuries: A global issue of protection.

Appendix 16. Complex ocular trauma outcomes and system capabilities: lessons from a combat zone and implications for national eye trauma care.

Appendix 17. Department of Defense and Eye Injury Data: Shedding New Light

Appendix 18. VFQ-25

Appendix 19. Mayo-Portland Adaptability Inventory (MPAI)

Appendix 20. Medical Outcomes 36-item short form survey (SF-36)



Ocular Trauma in Operation Iraqi Freedom and Operation Enduring Freedom from 2001 to 2011: A Bayesian Network Analysis

Morgan M. Harvey^a, Grant A. Justin^{b,c}, Daniel I. Brooks^d, Denise S. Ryan^e, Eric D. Weichelf^f, and Marcus H. Colyer^{c,g}

^aDepartment of Flight Medicine, Expeditionary Medical Facility, Camp Lemonnier, Djibouti; ^bDepartment of Ophthalmology, Brooke Army Medical Center, San Antonio, TX, USA; ^cDepartment of Surgery, Uniformed Services University, Bethesda, MD, USA; ^dDepartment of Statistics, Walter Reed National Military Medical Center, Bethesda, MD, USA; ^eWarfighter Refractive Eye Surgery Program and Research Center, Fort Belvoir, VA, USA; ^fRetina Group of Washington D.C., Greenbelt, MD, USA; ^gDepartment of Ophthalmology, Walter Reed National Military Medical Center, Bethesda, MD, USA

ABSTRACT

Purpose: To update the epidemiology of ocular injuries in soldiers admitted to Walter Reed Army Medical Center (WRAMC) from 2001 to 2011 after sustaining combat injuries in Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF).

Methods: Data were collected in the Walter Reed Ocular Trauma Database. A Bayesian Network Analysis was completed to better understand the relationships between different ocular demographic variables, injuries, surgeries, ocular trauma scores (OTS) and visual outcomes.

Results: There were 890 consecutive globe or adnexal combat injuries, or both, sustained by 652 United States soldiers treated at WRAMC between 2001 and 2011. The primary mechanism of injury was improvised explosive device (62.47%). Many patients (62.0%) had final visual acuity (VA) grades of 1–2 (20/15 – 20/200), while 29.9% of patients had final VA grades of 3–5 (less than 20/200), and 8.1% had unknown final VA grades. Bayesian Network Analysis revealed that the injury variables of Retina (47.9%), Lens (44.6%), Posterior Segment (43.7%) and Anterior Segment (40.3%), and the surgical variables of Enucleation (97.6%) and cataract extraction and posterior capsule intraocular lens placement (CEPCIOL; 43.3%) all had probabilities greater than 40% for a poor final VA, while all other variables were less than 40%.

Conclusion: Modern-day combat trauma results in complicated ocular injuries causing 30% of patients to be left legally blind in their injured eye. It is critical to maintain a wide variety of deployable, specialty trained ophthalmologists to ensure the best visual outcomes for wounded warriors and to maintain mission readiness.

ARTICLE HISTORY

Received 15 April 2020
Revised 8 September 2020
Accepted 18 September 2020

KEYWORDS

Ocular Trauma; Combat Injury; Operation Iraqi Freedom; Operation Enduring Freedom; Bayesian Network

Introduction

Combat ocular trauma represents a significant and increasing proportion of wartime injuries. The incidence of ocular trauma during nineteenth-century American conflicts was less than 1%,^{1,2} increased to 2.0–2.5% during World War I^{2–4} and II,^{1,2,4} rose to between 6 and 9.5% during the Vietnam War,² and reached 13% between 2002 and 2007 during Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF) (Table 1).¹⁹ The rate of ocular wartime injuries is disproportionately high considering that the eye represents approximately 0.5% of body surface area.²⁰ As improvised explosive devices (IED) and other weaponry have become more sophisticated, advancements in body armor have allowed soldiers to survive previously fatal chest and abdominal wounds, but have resulted in the relatively unprotected eyes being injured more often and more severely than other body parts,^{19–21} especially when ocular personal protective equipment is not worn.²²

This study provides an update to the epidemiology of ocular injuries in service members admitted to the former Walter Reed Army Medical Center (WRAMC) from 2001 to 2011 after sustaining combat injuries in OIF and OEF. The purpose of the study is to assess the sources and diverse types of ocular and extra-ocular injuries, wide array of surgeries performed, visual outcomes, late-term complications, and use of eye protection in soldiers injured in OIF and OEF combat during this time period. In addition, a Bayesian Network Analysis^{23–25} was completed to further analyze risk factors for a poor visual outcome.

Materials and methods

Study design

The Walter Reed Ocular Trauma Database (WROTD) is a retrospective case series of American OIF/OEF service members injured and evacuated to WRAMC between

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 Supplemental data for this article can be accessed on the publisher's website.

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Table 1. Types of Eye Injuries (%) from World War I to OIF and OEF.

War	Disorganized Eye Requiring Primary Enucleation ^ψ	Open Globe Injuries ^ς		Closed Globe Injuries ^β	External Eye Injuries ^α	Orbital & Lid Injuries ^ε	Others	Sample Size	References
		Total	With IOFB						
World War I	30.1	38.1	–	26.1	7.2	3.0	0.9	–	Duke Elder ¹
	–	19.1	–	–	–	–	–	1000	De Lapersonne ⁵
World War II	14.9	15.2	11.5	20.6	34.0	13.2	2.1	514	Dansey-Browning ⁶
	13.4	47.3	38.0	–	39.3	–	–	440*	Zorab ⁷
	17.3	42.6	24.1	24.1	16.0	–	–	301	Scott and Michaelson ⁸
	1.6	65.2	20.8	23.5	7.9	0.9	0.9	382	Sommerville-Large ⁹
	29.8	29.0	18.5	29.0	1.1	11.1	–	300	Bellows ¹⁰
Israeli-Arab	6.0	20.8	11.5	16.9	36.6	17.5	2.2	140	Treister ¹¹
	3.3	39.3	24.6	41.0	11.5	3.3	1.6	61	Gombos ¹²
Yom Kippur	12.3	42.0	38.3	24.7	7.4	13.6	–	–	Belkin ¹³
Vietnam	22.2	34.7	–	–	41.7	–	–	163	Hornblase ²
	21.8	24.4	15.1	8.4	27.7	17.6	–	119	Hoefle ¹⁴
Lebanon	13.6	21.0	12.3	25.9	27.2	8.6	3.7	–	Belkin et al ¹⁵
Iran-Iraq	5.0	33.7	10.5	42.8	10.7	2.4	5.4	3926	Lashkari ¹⁶
Desert Storm	Ω	8.2	8.2	20.9	5.6	24	11.7	160	Mader et al ¹⁷
Operation Iraqi Freedom	14.6	55.0	14.6	–	10.8	57.7	3.4	797	Thach et al ¹⁸
Current Study	12.3	38.0	16.7	43.7	67.9	86.2	41.3	890	Harvey et al

Parts of this table were reprinted from: Wong TY, Seet MG, Ang CL. Eye injuries in twentieth-century warfare: a historical perspective. *Surv Ophthalmol* 1997;41:433–59. Permission from Elsevier Received.

^ψA category no longer commonly reported with modern concepts in ocular trauma management

^ςIncludes all penetrating and perforating injuries, with or without a retained foreign body

^βDescribes nonpenetrating lacerations and contusive injuries, including hyphema, traumatic cataract, iridodialysis, commotio retinae, vitreoretinal hemorrhage and retinal detachment

^αRefers to all cases of corneal foreign body, corneal abrasions and conjunctival lesions

^εIncludes all orbital and adnexal injuries

^ΩData for this category not given in this report

IOFB = intraocular foreign bodies

^ψIncludes primarily neuro-ophthalmic injuries

2001 and 2011. Ophthalmologists evaluate patients in Iraq or Afghanistan at Combat Support Hospitals (CSH). Care en route at Landstuhl Regional Army Medical Center (LRMC) in Germany, as necessary, and then care at WRAMC was documented. Patients were then followed at WRAMC until they entered the Veterans Affairs medical system, returned to their unit or had a permanent change of duty station. Inpatient and outpatient records, transfer documentation, and operative reports were used to identify patients. The data were collected on Microsoft Excel (Microsoft Corporation, Redmond, WA) and stored on SPSS (IBM, New York, USA); R statistical software (R Foundation for Statistical Computing, Vienna, Austria) was then used for analysis. Further description of the collection of the data in the WROTD is outlined elsewhere.^{4,26}

Institutional Review Board (IRB) approval at Walter Reed National Military Medical Center was obtained. The study adhered to the guidelines of the Declaration of Helsinki. Informed consent was not completed as a HIPAA waiver by the IRB was granted due to deidentified collection.

Injury assessment

Injuries were classified as described by the Birmingham Eye Trauma Terminology.^{27–29} Snellen visual acuities (VA) were converted to vision grades for statistical analysis.^{4,30} Grade 1 was defined as 20/40 or better, Grade 2 was 20/50 to 19/200, Grade 3 was 20/200 to 1/200 (count fingers), Grade 4 was hand motion or light perception and Grade 5 was no light perception. The patients' ocular trauma scores (OTS) were calculated as described by Kuhn et al.³¹

Initial VA were assessed when the patients were first initially awake and able to complete a Snellen VA test. Due to the wartime trauma, patients frequently could not have their VA tested until after initial surgery and often not until they had arrived at WRAMC. For the entire dataset (n = 890); 55 were intubated and 44 eyes were missing data for initial VA. Per protocol, the post-injury VA was tested at the time range of 20 to 50 days post-injury, time range of 150 to 200 days post-injury and the last-documented VA date. Realistically, in many cases, only initial and final VA were obtained.

Bayesian network analysis

To learn the relationships between the variables in the dataset, a Bayesian Network Analysis was completed. First, we created a set of variable layers, in which lower level layers could logically inform higher level layers. Pooled variables within layers were defined using features defined by either a single variable or multiple variables from the WROTD (Table 2). The first layer of features included gender, whether or not the patient was wearing eye protection (EyeProt), and the geographic location of the injury (LocatInj; Iraq or Afghanistan). The second layer defined eight pooled injury categories (Plastic, Neuro-ophthalmic [Neuro], Cornea, Anterior Segment, Retina, Posterior Segment, Lens, and Associated Injury). The third layer included seven pooled surgical procedures Enucleation [Enucleation], Strabismus Surgery [StrabSurg], cataract extraction and posterior capsule intraocular lens placement [CEPCIOL], oculoplastic surgery (FX_Lid_Lac), vitreoretinal surgeries [PPV], penetrating keratoplasty [PKP], and glaucoma tube shunt placement [TubeShunt]). Finally, the last layer included the final visual outcome of the patient, grouped into some visual acuity (Grades 1, 2, or 3) and no visual acuity (Grades 4 or 5). A network blacklist was created which explicitly excluded from possible consideration any illogical (or backwards) associations; e.g., final visual outcome could never causally predict gender; or a particular type of surgery could never predict an incipient diagnosis.

Next, we generally followed the method of Scutari et al.³² Those variables and the blacklist of logical exclusions were analyzed by creating 1000 bootstrap bayesian

network replicates. To learn the structure of each network, the hill-climbing algorithm was used with the bayesian information criterion (BIC) score function. The probabilistic likelihood of an association between two variables appearing in the network (calculated as 'strength') and the hypothetical direction of that relationship ('direction') of each possible association was measured across all networks, and used to create a directed graph from associations that occurred at least 70% of the time. A plotting function was used to visualize the directed network. To test the accuracy of the network at informing predictions of Final Grade acuity, we used 20 runs of 10-fold cross-validation using the posterior classification error.

Only data with complete final visual grade were included in the model, leading to the exclusion of 72 of 890 patients. Due to the nature of the database creation, some classes of injury or surgery were not definitively recorded for each patient. Therefore, for the various injury and surgery categories, positive evidence was used to code each case a positive, whereas negative evidence or missing data were coded as negative.

Results

Demographics

Between 2002 and 2011, there were 890 eye injuries of 652 patients. Of these injuries, 745 (83.71%) occurred in Iraq and 145 (16.29%) in Afghanistan. Service component was recorded as follows: Unknown 88 (9.89%), US Army 627 (70.45%), Army National Guard 85 (9.55%), US Army Reserve 19 (2.13%), US Marine Corps 37

Table 2. Bayesian Variables.

Bayesian Variables Name	WROTD Variable Components used to build Bayesian Variables	Number of Eyes (n = 890)
Plastics	Adnexal Injury, Plastics Injury, Lacrimal Injury, Orbital Foreign Body, Orbital Fracture, Retrobulbar Hematoma, Enucleation Injury	567
Neuro	Neuro-ophthalmic Injury, Cranial Nerve Injury, Ptosis	363
Retina	Commotio, Chororetinal Rupture, Dialysis, IOFB, intraretinal hemorrhage, macular hemorrhage, subretinal hemorrhage, macular hole, retinal detachment, retinal tear	413
Cornea	Corneal abrasion, Corneal foreign body, corneal laceration, corneo-scleral laceration	326
Anterior Segment	Angle recession, conjunctival chemosis, glaucoma, hyphema, iridodialysis, iris injury, sphincter tear, zonular dehiscence	340
Lens	Lens injury	229
Posterior Segment	Choroidal hemorrhage, Choroidal rupture, Ophthalmic artery injury, posterior rupture, globe rupture, scleral laceration, vascular injury, vitreous hemorrhage	372
Associated Injuries	Associated injury, extremity injury, amputation, abdominal injury, facial injury, neck injury, pelvic injury, skull fracture, traumatic brain injury, thorax injury	782
Enucleation	Enucleation	109
FX_Lid_Lac	Orbital Fracture repair, Ptosis surgery, Lid reconstruction, Lacrimal Surgery	101
PPV	PPV, scleral buckle, PPL, IOFB removal	203
CEPCIOL	CEPCIOL	67
PKP	PKP	33
Tube Shunt	Tube shunt	8
StrabSurg	Strabismus Surgery	14

Legend: FX_Lid_Lac- Fractures, Eyelid Injuries and Lacerations, PPV- pars plana vitrectomy, PPL- pars plana lensectomy, IOFB- intraocular foreign body removal, CEPCIOL- cataract extraction and posterior chamber intraocular lens insertion, PKP- penetrating keratoplasty

Table 3. Combat Ocular Trauma Demographics.

Age (yrs)	Mean, 27.2 (range, 18–53)
Gender	862 (96.85%) male/28 (3.15%) female
Documented eye protection	243 (27.30%)
Documented without eye protection	223 (25.06%)
Unknown use of eye protection	424 (47.64%)
Mechanism of injury	
Improvised explosive device (IED)	556 (62.47%)
Rocket-propelled grenade (RPG)	103 (11.57%)
Motor vehicle accident	42 (4.72%)
Gunshot wound	70 (7.87%)
Mine	27 (3.03%)
Mortar	32 (3.60%)
Helicopter crash	5 (0.56%)
Grenade	28 (3.15%)
Tank fire	2 (0.25%)
Other	24 (2.70%)
Unknown	1 (0.11%)
Unilateral	412 (46.29%)
Bilateral	478 (53.71%)
Globe/globe injury	332 (37.30%)
Globe/adnexa	80 (8.99%)
Adnexa/adnexa	34 (3.82%)
Neuro/neuro	22 (2.47%)
Globe/neuro	10 (1.12%)

(4.16%), Air Force 19 (2.13%), DoD Civilian 7 (0.79%), and Other 8 (0.9%). Time from injury to CSH was hours in 676 (75.96%), days in 52 (5.84%) and unknown in 162 (18.20%). Age, gender, use of eye protection, source of injury and injury patterns are summarized in [Tables 3](#) and [4](#). [Table 5](#) contains the surgeries performed and [Figure 1](#) describes the order that the surgeries were performed at the CSH.

Table 4. Injuries.

Closed Globe	389 (43.71%)
Zone 1	141 (15.84%)
Zone 2	35 (3.93%)
Zone 3	213 (23.93%)
Open Globe	338 (37.98%)
Zone 1	79 (8.88%)
Zone 2	58 (6.52%)
Zone 3	201 (22.58%)
Occluoplastic	480 (53.93%)
Adnexal only	108 (12.13%)
Retrobulbar hematoma	37 (4.16%)
Lid injury	286 (32.13%)
Enophthalmos	14 (1.57%)
Orbital fracture	294 (33.03%)
Intraorbital foreign body	137 (15.39%)
Ptoxis	11 (1.24%)
Lacrimal Injury	17 (1.91%)
Neuro-ophthalmic	193 (21.69%)
Afferent pupillary defect	157 (17.64%)
Direct optic nerve injury	79 (8.88%)
Optic nerve avulsion	13 (1.46%)
Diplopia	45 (5.06%)
Cranial nerve injury	69 (7.75%)
Horner's syndrome	5 (0.56%)
Anterior segment	
Conjunctival chemosis	73 (8.20%)
Corneal abrasion	60 (6.47%)
Corneal laceration	127 (14.27%)

(Continued)

Table 4. (Continued).

Closed Globe	389 (43.71%)
Corneal foreign body	138 (15.51%)
Corneo-scleral laceration	78 (8.76%)
Scleral laceration	128 (14.38%)
Hyphema	168 (18.88%)
Iritis	24 (2.70%)
Iris injury	161 (18.09%)
Sphincter tear	28 (3.15%)
Iridodialysis	77 (8.65%)
Angle injury	75 (8.43%)
Angle recession	20 (2.25%)
Cyclodialysis cleft	5 (0.56%)
Zonular dehiscence	40 (4.49%)
Traumatic cataract	198 (22.25%)
Aphakic	14 (1.46%)
Lens dislocation	15 (1.69%)
Subluxated vitreous	3 (0.34%)
Glaucoma	16 (1.80%)
Retina and posterior segment	
Globe rupture	35 (3.93%)
Posterior orbital rupture	29 (3.26%)
Intraocular foreign body (IOFB)	166 (18.65%)
Vitreous hemorrhage	332 (37.30%)
Vitreous avulsion	6 (0.67%)
Retinal hemorrhage	
Subretinal hemorrhage	148 (16.63%)
Intraretinal hemorrhage	135 (15.17%)
Macular hemorrhage	89 (10.00%)
Traumatic retinal tear	179 (20.11%)
Traumatic retinal detachment	143 (16.07%)
Macula-on retinal detachment	35 (3.93%)
Macula-off retinal detachment	95 (10.67%)
Traumatic macular hole	27 (3.03%)
Comotio retinae	126 (14.16%)
Comotio retinae involving the macula	95 (10.67%)
Chorioretinal rupture (sclopetaria retinis)	84 (9.44%)
Chorioretinal rupture involving the macula	42 (4.72%)
Choroidal hemorrhage	125 (14.04%)
Choroidal hemorrhage involving the macula	80 (8.99%)
Choroidal rupture	37 (4.16%)
Choroidal rupture involving the macula	23 (2.58%)
Choroidal and retinal vascular injury	13 (1.46%)
Ophthalmic artery injury	7 (0.79%)
Central retinal artery occlusion	1 (0.11%)
Branch retinal artery occlusion	4 (0.45%)
Central retinal vein occlusion	0 (0.00%)
Branch retinal vein occlusion	0 (0.00%)
Late Complications	
Cystoid macular edema	19 (2.13%)
Postoperative proliferative vitreoretinopathy	75 (8.54%)
Phthisis bulbi	44 (4.94%)
Endophthalmitis	2 (0.22%)
Postoperative endophthalmitis	1 (0.11%)
Fungal endogenous endophthalmitis	1 (0.11%)
Corneoscleral scars	98 (11.01%)
Band keratopathy	4 (0.45%)
Associated Injuries	
Traumatic brain injury (TBI)	395 (40.34%)
Skull fracture	130 (14.61%)
Neck injury	40 (4.49%)
Face injury	515 (57.87%)
Neurologic injury	258 (28.99%)

Visual acuities and ocular trauma score

Initial and final VA and OTS score were recorded ([Table 6](#) and Supplemental Table 1). The majority of patients (62.02%) had final VA grades of 1–2 (20/15 – 20/200), while 29.89% had final VA grades of 3–5 (less than 20/200) and 8.09% had unknown final VA

Table 5. Surgeries.

PPV ^a	197 (22.13%)
SB ^b	23 (2.58%)
PPL ^c	119 (13.37%)
CEPCIOL ^d	67 (7.53%)
IOFB ^e removal	118 (13.26%)
Enucleation	109 (12.25%)
Fracture repair	45 (5.06%)
PKP ^f	33 (3.71%)
Tube shunt placement	8 (0.90%)
Ptois surgery	7 (0.79%)
Lid reconstruction	49 (5.51%)
Nasolacrimal system repair	7 (0.79%)
Strabismus surgery	14 (1.57%)
Primary surgeries	
Exploration/repair	300 (33.71%)
Lateral canthotomy and cantholysis	18 (2.02%)
Primary enucleation	53 (5.96%)
Secondary surgeries	
Exploration/repair	3 (0.34%)
Lateral canthotomy and cantholysis	13 (1.46%)
Primary enucleation	4 (0.45%)
IOFB ^e removal	2 (0.22%)
Orbital foreign body removal	1 (0.11%)
Tertiary surgeries	
Exploration/repair	2 (0.22%)
Lateral canthotomy and cantholysis	4 (0.45%)
Quaternary surgeries	
Exploration/repair	1 (0.11%)
Scleral repair	1 (0.11%)

^aPars plana vitrectomy^bScleral buckling^cPars plana lensectomy^dCataract extraction with posterior intraocular lens implantation^eIntraocular foreign body^fPenetrating keratoplasty

grades. The changes in VA between initial and final VA were as follows: no change in 350 (39.33%), improved in 341 (38.31%), decreased in 45 (5.06%). There were 99 (11.12%) eyes with unknown initial VA, 55 (6.18%) of these were due to patients initially being intubated. An afferent pupillary defect (APD) was noted in 157 (17.64%) eyes.

Table 6. Visual Acuity Grades.

VA ^a	VA ^a Grade	Initial VA ^a Grade (number of eyes)	Final VA ^a Grade (number of eyes)
No Light Perception	Grade 5	140 (15.73%)	162 (18.20%)
Light Perception	Grade 4	165 (18.54%)	59 (6.63%)
Hand Motion			
Count Fingers	Grade 3	64 (7.19%)	45 (5.06%)
20/800			
20/400			
20/200	Grade 2	94 (10.56%)	59 (6.63%)
20/100			
20/80			
20/70			
20/60			
20/50			
20/40	Grade 1	328 (36.85%)	493 (55.39%)
20/30			
20/25			
20/20			
20/15			
Unknown	Unknown	99 (11.12%)	72 (8.09%)

^aVisual acuity

Bayesian network analysis

The averaged, bootstrapped Bayesian network (Figure 2) was used to visualize and compute the directed interdependency between the variables. The derived strengths and directions of each association are also reported in Supplemental Table 2. Most of the 20 above threshold relationships in the network were strong, with only the association between Lens Injury and Posterior Segment Injury (Strength = .76) appearing in less than 80% of networks, and only five others appearing in less than 98.5% of networks. However, there were several variables that had challenging to ascertain directional associations, mainly involving the possible relationships between various injury categories, especially Anterior and Posterior Segment injuries. This may reflect the more unclear causal relationships

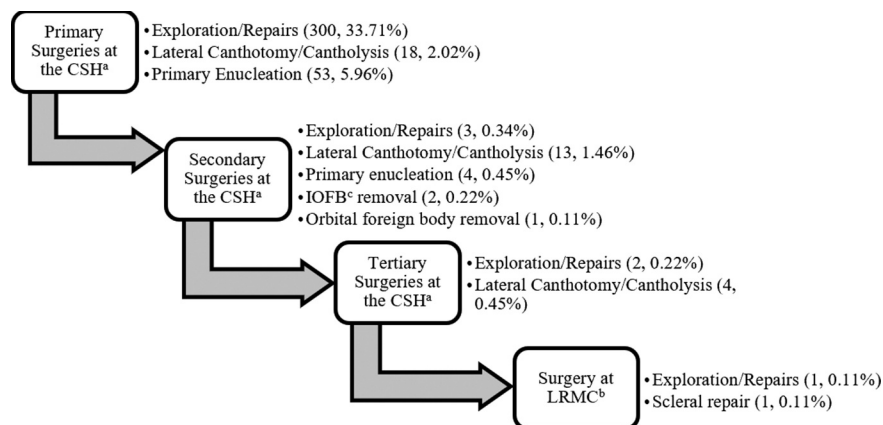


Figure 1. Surgeries performed in a Combat support hospital or at Landstuhl regional medical center. (a) Combat Support Hospital, (b) Landstuhl Regional Medical Center, ^cIntraocular foreign body.

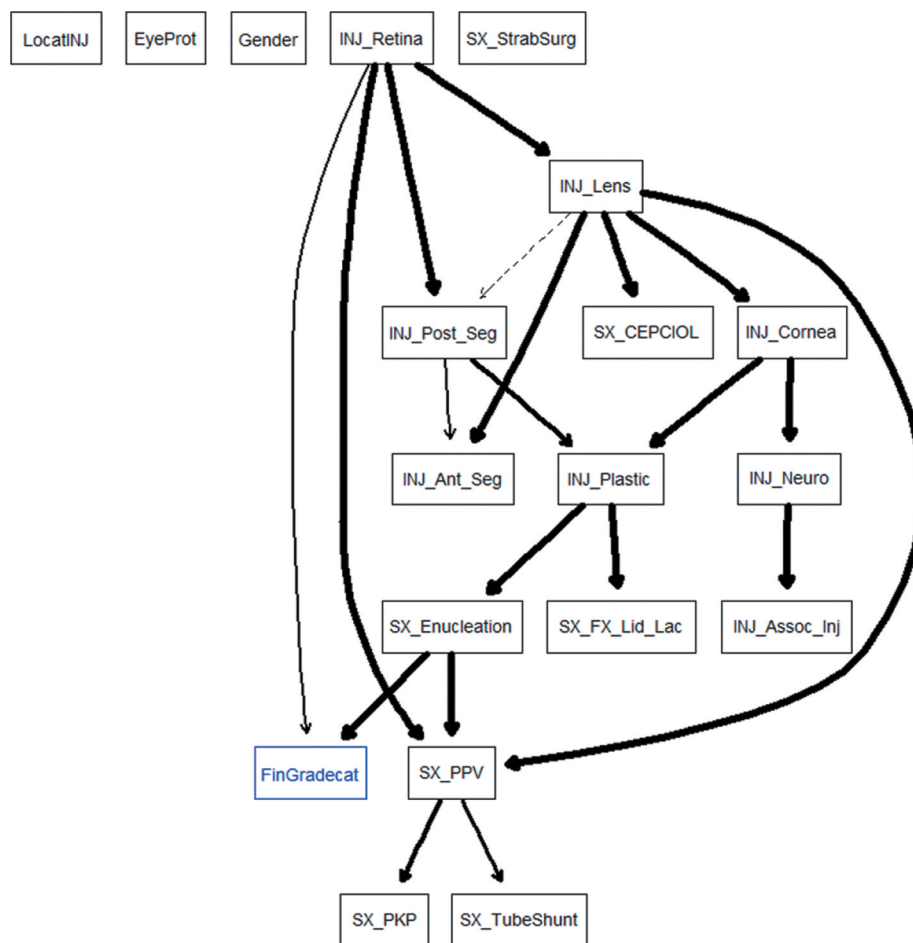


Figure 2. Bayesian Network Analysis. See Table 2 for WROTD variables used to build Bayesian Analysis variables. Size of the lines corresponds to strength of association (see Supplemental Table 2).

between various injury categories and more clearly observable pathways between both injury and surgery and injury and outcome. Perhaps surprisingly, only two variables were directly linked to the outcome of final visual acuity: a retinal injury and enucleation surgery, with all other associations to final visual outcome flowing through these two important links.

Four variables were left out of the model entirely: gender, the geographic location of the injury, strabismus surgery, and whether or not eye protection was worn. While both gender (97.3% male) and strabismus surgery (1.6%) were highly imbalanced features, geographic location and eye protection seemed to have little impact for predicting any other features of an individual patient's diagnosis or treatment.

A crossvalidation strategy was used to evaluate the network's performance in evaluating final visual outcome. Here, we compared the network's crossvalidated loss (19.8%) to a randomly generated network (30.7%). Because of the imbalance in Final Grade (most patients, 67.5%, had some perceptible visual acuity), there was a corresponding imbalance in identifying poor expected

outcomes as compared to identifying good visual outcomes.

The model did find that certain variables had a higher probability of a final visual acuity less than 20/200. The injury variables of Retina (47.9%), Lens (44.6%), Posterior Segment (43.7%) and Anterior Segment (40.3%), and the surgical variables of Enucleation (97.6%) and CEPCIOL (43.3%) all had probabilities greater than 40%, while all other variables were less than 40%.

Discussion

Ocular trauma significantly affects not only the military mission, but also has profound social^{30,33} and economic consequences.³⁴ Only 25% of American eye casualties in Vietnam were able to return to active duty,^{35,36} and the U.S. Library of Congress estimated the ultimate cost of serious eye injuries from the Vietnam War to be four billion dollars.^{2,36} Furthermore, according to data from 2000 to 2010, the total incident cost of eye injuries in the military each year was 2.282 USD billion.³⁴

This study describes the most comprehensive database of wartime ocular trauma in reported history and the largest database of ocular trauma in OIF/OEF, detailing all ocular injuries and their causes and management from 2001 to 2011. Comparison of eye injuries among different wars is challenging given the ambiguity in definition and lack of a recognized standard classification of ocular trauma.³⁷ Not all data are complete, and data from previous wars are often based merely on personal observations and impressions. In this study, the classification proposed by Kuhn et al.³⁷ and utilized by Wong et al.³⁶ has been adopted to compare ocular injury rates in different wars (Table 1). This study showed that modern-day combat trauma results in complicated ocular injuries causing 30% of patients to be left blind in their injured eye. Further, the injuries following under the variables of Retina, Posterior segment, Anterior segment and Lens were most strongly associated with a poor visual prognosis.

The main etiologies of eye injuries have changed over the past century with advances in techniques and weaponry. There was a significant shift in the primary cause of eye injuries in OIF/OEF, as it was the first major war where explosive devices were the main cause of ocular injuries.^{18,38–40} In the early phases of World War I, gunshot wounds accounted for up to 60% of ocular trauma, and over 50% of these injuries were associated with orbital fractures.^{3,36,38} With the development of long-range artillery in the later years of World War I and in World War II, shell fragmentation injuries from tank and artillery became more prevalent, accounting for 50–80% of ocular injuries, while injuries from short-range weapons became less common.^{18,36,38} During OIF/OEF, explosive devices were the leading cause of ocular trauma, causing 51–73% of ophthalmic injuries.^{18,38–40}

Explosive devices not only frequently result in severe bodily injuries, but often lead to unique ocular injuries not commonly seen with the gunshot wounds and shell fragmentation trauma of previous wars. Ocular injuries caused by IEDs commonly involve avulsed portions of lid, sclera or cornea, and wound edges that are ragged and extremely difficult to repair. In addition, explosions produce numerous fragments that impact the globe and adnexa and are frequently contaminated by secondary projectiles such as stones, glass, metal or plastic.^{18,38} These blast injuries present unique challenges to twenty-first-century deployed ophthalmologists, who primarily remove eyes only if they are functionally destroyed with no possibility of visual or cosmetic rehabilitation.¹⁸

Despite the increasing severity of ocular trauma with modern-day warfare, the number of eyes requiring primary enucleation has decreased significantly as our

capacity to repair injured eyes surgically has improved. The rate of ocular injury requiring enucleation steadily declined from 50% in World War I, to 35–40% in World War II, to 27% in the Korean War, and has remained around 13–20% through the Vietnam War, Yum Kippur (1973) and Lebanon Wars (1982), Operation Desert Storm and to the present.^{18,38} One British study from OEF/OIF found the rate of enucleation to be 11.11%,³⁹ while in the current study it was 12.25%. Another recent study demonstrated that host nation civilians in OIF/OEF had a high odds of undergoing an enucleation.⁴⁰ With a significant decrease in the number of enucleations performed, there has been an increase in other eye-sparing surgeries with pars plana vitrectomy (22.13%), pars plana lensectomy (13.37%) and intraocular foreign body removal (13.26%) all being more commonly performed than enucleation (12.25%) in OIF/OEF (Table 5). Further, with retinal and posterior segment surgeries being performed more than enucleations (22.81%) and other oculoplastic surgeries (fracture repair, ptosis surgery, lid reconstruction and nasolacrimal system repair; 11.35%) being performed approximately as frequently as enucleations, followed closely by cataract extraction with posterior intraocular lens implantation (CEPCIOL) (7.54%), it is evident that a variety of ophthalmic subspecialists are required in the deployed setting.

Notwithstanding significant advances in ocular trauma management, increasingly sophisticated destructive forces have resulted in complex ocular injuries, often affecting multiple ophthalmic structures. The current study found an open globe rate of 37.98% and another previous British study found a rate of 33.33%,³⁹ while a more recent study from OIF/OEF have noted open globe injury incidence as high as 56%.⁴⁰ Significantly, closed globe, external, adnexal and neuro-ophthalmic injuries appear to be much more common in twenty-first-century warfare (Table 1). At 43.71%, closed globe injuries (all nonpenetrating lacerations and contusive injuries, including hyphema, traumatic cataract, iridodialysis, commotio retinae, vitreoretinal hemorrhage and retinal detachment) were more common in OIF/OEF than in any prior conflicts. Similarly, external eye injuries, which include all cases of corneal foreign bodies, corneal abrasions and conjunctival lesions were at a high of 67.87%, and orbital and adnexal injuries were at a high of 86.17%. There is minimal data on the rate of neuro-ophthalmic injuries in prior conflicts, but 41.35% of eyes in OIF/OEF suffered from neuro-ophthalmic injuries. The increased documentation of these additional injuries may be due in part to the database described in this study being more systematic, complete and thorough than earlier

studies. In addition, as the acumen of ophthalmic knowledge and the ability to repair seemingly devastating injuries have increased, there may be more documentation of injuries to eyes that previously would have been removed without thorough recording of all ocular trauma. Regardless, explosive forces have likely contributed to increasing the number of closed globe, external, adnexal and neuro-ophthalmic injuries. The sheer force of blast injuries as well as the shrapnel and secondary projectiles have undoubtedly played a significant role in these increased injury rates. In addition, blast injuries have resulted in a high rate of associated extra-ocular injuries, with face injuries (57.87%), traumatic brain injuries (TBIs) (40.34%) and neurologic injuries (28.99%) being the most common (Table 4).

The Bayesian Network Analysis (Table 2, Figure 2, Supplemental Table 2) provides insight into what types of risk factors, injuries and surgeries were associated with the worst visual prognosis, specifically final VA grades of 3 to 5 (less than 20/200), which were seen in 29.89% of patients. The injury category most strongly associated with poor VA was Retina (47.9%), followed by Lens (44.6%), Posterior Segment (43.7%) and Anterior Segment (40.3%). This is of particular note, as closed globe injuries, which include many retinal, lens and posterior segment injuries, increased significantly in OIF/OEF (Table 1). This further emphasizes the importance of having the appropriate ophthalmic subspecialists readily available in the combat setting. Oculoplastic, neuro-ophthalmic and corneal injuries were less strongly associated with a poor visual prognosis. In addition, the associated extra-ocular injuries detailed in Table 4 were not as strongly associated with a poor visual prognosis. Unsurprisingly, enucleation was the variable most strongly associated with a poor visual prognosis at 97.6% with VA less than 20/200. The only other surgery strongly associated with poor VA was CEPCIOI (43.3%).

The limitations of this study include incomplete records and loss to follow-up. In particular, VAs often could not be tested until after initial surgery or not until arrival at WRAMC, or VAs could not be obtained due to the patient being intubated. There was also limited long-term tracking once the soldiers left the military health system. Thus, it is possible that the ultimate final recorded VAs were worse than documented or that additional complications arose that were excluded from this analysis. Therefore, this data reflects severe, early eye injuries rather than chronic and progressive ocular diseases that result from combat trauma. In addition, as final visual acuity grade was not available in 72 patients, and these patients were excluded from the model, there is inclusion bias. The patients with missing final visual acuity data could have represented those

with more serious systemic injuries or those that were moved to a different hospital system quickly, such as those with significant burns to Brooke Army Medical Center in San Antonio, TX. There is also incomplete data on the use of eye protection with 47.64% of soldiers with unknown use of eye protection. Although it is presumed that the use of eye protection would reduce many of the injuries described in this study, this cannot be proven or disproven by the available data.

In summary, as twenty-first-century warfare evolves, ocular and extra-ocular injuries have become more complex, but the ability to perform vision sparing surgeries has also improved. Thus, having increased surgical capabilities at the CSH level (Figure 1) has become of vital importance to ensure the best visual and cosmetic outcomes for troops. The majority of these eye sparing surgeries require prompt management that should not be delayed for evacuation to a larger military health facility in Europe or the US (LRMC or WRAMC), and soldiers often have other life-threatening injuries and are too unstable for prompt evacuation. This emphasizes the importance of deployed ophthalmologists and subspecialists at CSHs in order to provide the best care to wounded warriors.

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Disclaimer

The view(s) expressed herein are those of the author(s) and do not reflect the official policy or position of Brooke Army Medical Center, the Defense Health Agency, the U.S. Army Medical Department, the U.S. Army Office of the Surgeon General, the Department of the Air Force, the Department of the Army, Department of Defense, the Uniformed Services University of the Health Sciences or any other agency of the U.S. Government.

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No conflicting relationship exists for any author

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Ethics statement

Institutional Review Board approval at Walter Reed National Military Medical Center was obtained. The study adhered to

the Declaration of Helsinki. Informed consent was not completed as a HIPAA waiver was granted due to deidentified collection.

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Presentation

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Causes of combat ocular trauma-related blindness from Operation Iraqi Freedom and Enduring Freedom

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BACKGROUND:	The incidence of eye injuries in military service members is high in the combat setting. This is the first study that identifies the primary reason for poor visual acuity (worse than 20/200).
METHODS:	This is a retrospective, noncomparative, interventional case series analyzing US Operation Iraqi and Enduring Freedom members who were evacuated from the theater of operations to Walter Reed Army Medical Center from 2001 through 2011. Primary outcome measures were the length of follow-up, globe survival, and anatomic causes of blindness. Secondary outcome measures included surgical procedures performed, use of eye protection, nonocular injuries, incidence of traumatic brain injury, source of injury, visual outcomes, and predictability of Ocular Trauma Score (OTS) on visual outcome. Univariate analysis was performed using χ^2 and Fisher's exact test. A $p < 0.01$ was considered significant because of the multiple hypotheses tested.
RESULTS:	There were 265 eyes of 239 patients who had final best-corrected visual acuity of worse than 20/200. The average age was 27.4 years (range, 19–53 years). Of the patients, 97.5% were male, and 28.9% had documented use of eye protection. The average follow-up was 350.19 days (range, 3–2,421 days). There were 128 right-eye and 133 left-eye injuries, with a total of 26 bilateral injuries. There were 206 open-globe and 56 closed-globe injuries, which were further subdivided into zones. Open-globe Zone III injuries (81.6%) were the number one cause of blindness, and most injuries were caused by improvised explosive devices (64.2%). Enucleation was the most common surgery performed (40.6%) and therefore the leading cause of blindness, followed by a multifactorial cause and direct traumatic optic neuropathy.
CONCLUSION:	Ocular trauma is common among combat injuries. Close to a third of service members that experience an ocular trauma become legally blind. Further research is needed to focus on strategies to prevent injury and improve visual outcomes. (<i>J Trauma Acute Care Surg.</i> 2015;79: S210–S215. Copyright © 2015 Wolters Kluwer Health, Inc. All rights reserved.)
LEVEL OF EVIDENCE:	Prognostic/epidemiologic study, level V.
KEY WORDS:	Combat ocular trauma; closed-globe injury; open-globe injury; blindness.

Despite the advancements in modern warfare and armaments, ocular injuries continue to constitute a significant proportion of morbidity for military service members.¹ Between 2002 and 2007, the documented number of US soldiers involved in Operation Iraqi and Enduring Freedom (OIF/OEF) that were evacuated and had a significant ocular injury was 13%.^{2,3} The analysis of visual outcomes of all combat ocular trauma patients during OIF/OEF that were evacuated

to Walter Reed Army Medical Center (WRAMC) was published, demonstrating the severity and visual potential from different types of injuries.^{4–6} The studies demonstrated the obvious need for eye protection and that the nature and the consequences of the initial injury play a key role in the final visual acuity. There has not been a previous study that identifies the primary reasons of poor visual acuity (worse than 20/200) in OIF/OEF members.

PATIENTS AND METHODS

This study reviews the reasons soldiers evacuated to WRAMC between 2001 and 2011 had the final best-corrected visual acuity (BCVA) of worse than 20/200. It is a retrospective, noncomparative, interventional case series analyzing US OIF/OEF service members who were evacuated from the theater of operations to WRAMC, Washington, DC, from 2001 through 2011. Ophthalmologists at combat support hospitals in Iraq or Afghanistan first examined and, when necessary, surgically treated the patients. Some soldiers were taken to Germany where they were further stabilized to finally be transported to WRAMC. The patients were followed up at WRAMC during their convalescence, some until their return to duty, and some until their permanent change of station or to the time of discharge into the Veteran's Affairs medical system. As part of an ongoing institutional review board–approved protocol, the investigators have maintained an eye trauma

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Portions of this study were submitted for presentation at the Military Health System Research Symposium, August 2014, in Fort Lauderdale; American Society of Retinal Specialists, August 2014; and Annual Research in Vision and Ophthalmology, May 2014, in Orlando, Florida. This article has not otherwise been previously presented or published.

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TABLE 1. Summary of the Studied Cohort of Patients With Combat Ocular Trauma With BCVA Worse Than 20/200

Age, y	27.44 ± 7.67 (19–53)
Sex	97.5%, male; 2.5%, female
Days of Follow-up	350.19 ± 407.953 (3–2,421)
Eye Protection	69 (28.9%)
Laterality	
Right eye	129 (48.5%)
Left eye	133 (50.0%)
Bilateral	26 (9.77%)
Mechanism of injury	
IED	170 (64.2%)
RPG	29 (10.9%)
Gunshot wound	27 (10.2%)
Other	14 (5.3%)
Grenade	9 (3.4%)
Mine	6 (2.3%)
Mortar	6 (2.3%)
Motor vehicle crash	3 (1.1%)
Helicopter crash	1 (0.4%)
Type of injury	
Phthisis bulbi	44 (18.7%)
Retinal detachments	117 (51.5%)
Direct optic neuropathy	62 (26.6%)
Open globe	206 (77.7%)
Closed globe	56 (21.1%)
IOFB	63 (23.8%)
TBI	123 (46.4%)
Surgeries	
Enucleations	108 (40.6%)
Pars plana vitrectomy	89 (37.2%)
Pars plana lensectomy	67 (28%)
IOFB removal	38 (16.4%)
Penetrating keratoplasty	23 (9.6%)
Laser retinopexy	21 (7.9%)
Scleral buckle	15 (5.7%)
Cataract extraction	13 (5.5%)
Graft failure	12 (5.5%)

database, the Walter Reed Ocular Trauma Database (WROTD) since 2007. The WROTD includes all ocular trauma patients seen at WRAMC between 2001 and 2011, when WRAMC closed. Since August 2011, all patients have been treated at the Walter Reed National Military Medical Center in Bethesda, MD. This data set does not include Walter Reed National Military Medical Center patients. Patients were identified for inclusion into the

WROTD from a Global War on Terrorism database developed and maintained by the WRAMC Ophthalmology Service since the onset of IOF in 2003. Inpatient records, outpatient records, transfer summaries, operative reports, and all other available existing data on each patient were collated into a study file. Information then was recorded onto a standardized data collection sheet used for data entry into a structured database program for analysis (SPSS software version 21.0, SPSS, Inc., Chicago, IL). Data collection included variables from the time of injury to the end of follow-up. Primary outcome measures include length of follow-up at WRAMC, globe survival, and anatomic causes of blindness. Secondary outcome measures include surgical procedures performed, use of eye protection, nonocular injuries, incidence of traumatic brain injury (TBI), source of injury, visual outcomes, and predictability of Ocular Trauma Score (OTS) on visual outcome.

Inclusion criteria were American soldiers injured during OIF/OEF in Iraq or Afghanistan who had final a BCVA worse than 20/200. Exclusion criteria were nonbattle injuries or injuries sustained outside a combat zone or ocular trauma in Iraqi or Afghan civilians or any other non-American soldier/civilian. Patients with visual acuity 20/200 or better were excluded from the analysis. Injuries were classified according to Birmingham Eye Trauma Terminology.^{7,8} The OTS was calculated as described by Kuhn et al.⁷ The initial and final visual acuities were converted from Snellen acuity to vision grades for statistical analysis.³ Grade 1 was visual acuity of 20/40 or better. Grade 2 was 20/50 to 20/200. Grade 3 was BCVA of 19/200 to 1/200 (count fingers). Grade 4 was hand motion/light perception, and finally, Grade 5 was no light perception. An eye was considered “blind” if the vision was worse than 20/200 (Grades 3–5).

The final visual acuity was assessed at separate visits on 30, 60, and 180 days after arrival to WRAMC or at their discharge from the system. In addition, some patients were followed up long term, and results for patients with more than 365 days of follow-up will be provided.

Initial visual acuity was documented at the first encounter with the patient when awake. When data were available from the theater, the initial visual acuity in the combat support hospital was used. Often, visual acuities were not recorded at the time of initial surgery. In these cases, visual acuity upon arrival to WRAMC was recorded. Soldiers were seen in the ophthalmology clinic, or for those who were immobile, the initial examination was conducted bedside in the surgical intensive care unit. Visual acuity in immobile soldiers was obtained at the bedside using a Rosenbaum pocket screener at 14 in. Acuity measurements were taken with a standard Snellen eye chart using best spectacle acuity when possible. Visual acuity measurements were taken once the soldier was able to

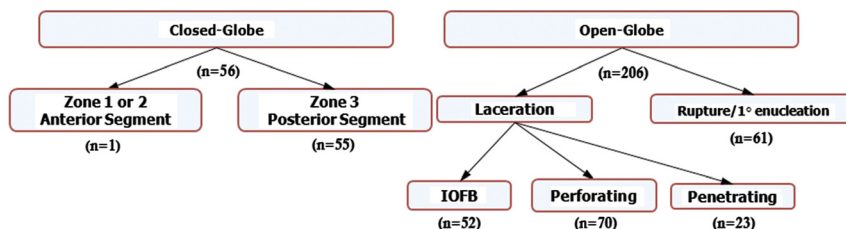


Figure 1. Classification of injuries in combat ocular trauma.

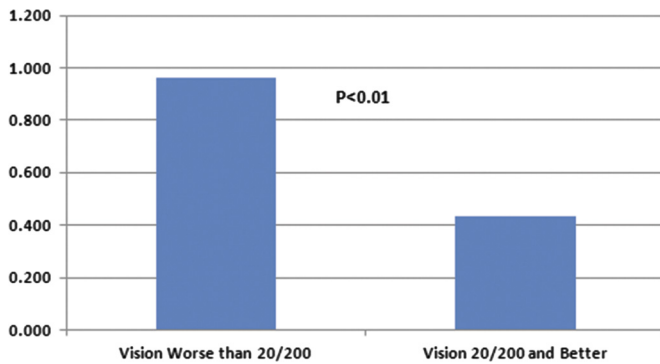


Figure 2. Comparison of surgeries per eye between eyes with final vision of worse than 20/200 versus 20/200 or better.

communicate; if they had to be intubated, initial visual acuity was assessed upon extubation. The data for all adnexal injuries either isolated or involving the globe were also collected. Bilateral ocular injuries were classified according to the description of Weichel and Colyer,³ as were the nonocular injury subclassifications.

Univariate analysis was performed using χ^2 and Fisher's exact test, with p value less than 0.01 being statistically significant, because multiple hypotheses were tested and statistical significance had to be adjusted.

RESULTS

Between 2001 and 2011, there were 895 eyes of 654 soldiers evacuated from Iraq and Afghanistan to WRAMC with ocular injuries; 265 eyes (29.7%) of 239 patients had a final BCVA worse than 20/200. The average age was 27.4 years (range, 19–53 years), and 97.5% were male. The use of eye protection was determined to be 28.9% of the known 188 patients analyzed; the remainder of the patients ($n = 51$) had

missing data; in addition, there were missing pieces of information for other variables, such as the number of retinal detachments, number of optic neuropathies, and so on. As seen in Table 1,^{3,4} the majority of injuries were the result of a blast and fragmentation. The average days of follow-up were 350.19 (range, 3–2,421). There were 128 right-eye and 133 left-eye injuries; 1 was right adnexal-only injuries, 1 was right neuroophthalmologic, and 1 was left neuroophthalmologic injury, with a total of 26 bilateral injuries. The majority of eyes only underwent one surgery ($n = 88$, 33.1%); 30 eyes (11.3%) underwent two surgeries, and 9 eyes (3.4%) underwent three or more surgeries. The most common surgery was enucleation at 108 eyes (40.8%), followed by pars plana vitrectomy in 89 eyes (33.6%), as seen in Table 1. Four eyes (1.5%) underwent globe repair surgery once at WRAMC, while the remainder, 261 eyes, was repaired or enucleated before arrival at WRAMC.

A detailed classification of combat ocular trauma injuries can be seen in Figure 1.^{3,5} Amid the entire sample of 265 blind eyes, as defined by BCVA worse than 20/200, there were 206 open-globe (77.7%) and 56 closed-globe (21.1%) injuries, 1 (0.4%) classified as adnexal and 2 eyes (0.8%) with neurologic injuries. The neural and adnexal injuries were left blind due to the multifactorial nature of their injuries, namely, associated facial injury, cranial nerve injury, and TBI. In attempt to improve the visual outcome in the wounded soldiers, there were a total of 225 surgical procedures performed, not including enucleations. When comparing the 225 surgeries in eyes worse than 20/200 to the 198 surgeries performed in the 629 eyes with final BCVA of 20/200 or better, there were 2.2 times more surgeries per eye performed in the cohort with worse than 20/200 ($p < 0.01$), as seen in Figure 2. Among all open-globe injuries, there were 16 Zone I injuries (7.8%), 22 Zone II injuries (10.7%), and 168 Zone III injuries (81.6%), as summarized in Table 2. As shown in Figure 3, the incidence of blindness was higher in injuries sustained to Zone III, with an odds ratio of 13.6 of becoming blind if injury occurred to an open-globe Zone III,

TABLE 2. Classification of Injuries Based on Zones Involved

	Zone I		Zone II		Zone III	
	Closed Globe	Open Globe	Open Globe	Closed Globe	Open Globe	Closed Globe
Total no. Eyes Injured	16	0	22	1	168	55
Retinal detachment	5 (31.2%)	0	7 (31.8%)	0	94 (56%)	11 (20%)
Direct optic nerve injury	1 (6.3%)	0	5 (22.7%)	0	27 (16.1%)	27 (49.1%)
Optic nerve avulsion	0	0	1 (4.5%)	0	6 (3.64%)	5 (9.1%)
Choroidal hemorrhage	6 (37.5%)	0	6 (27.3%)	0	91 (54.2%)	7 (12.7%)
Macula involved	3 (18.5%)	0	6 (27.3%)	0	9 (5.4%)	7 (12.7%)
Corneal laceration	15 (93.8%)	0	4 (18.2%)	0	23 (13.7%)	2 (3.6%)
Corneoscleral laceration	1 (6.3%)	0	15 (68.2%)	0	37 (22%)	1 (1.8%)
Surgeries						
Enucleation	2 (12.5%)	0	4 (18.2%)	0	102 (60.7%)	0
Pars plana vitrectomy	8 (50%)	0	13 (59.1%)	0	54 (32.1%)	14 (25.5%)
Scleral buckle	1 (6.3%)	0	0	0	11 (6.5%)	3 (5.5%)
IOFB removal	6 (37.5%)	0	6 (27.35)	0	26 (15.5%)	0
Pars plana lensectomy	6 (37.5%)	0	7 (31.8%)	0	43 (25.6%)	11 (20%)
Globe exploration WRAMC	1 (6.3%)	0	3 (13.6%)	0	10 (5.95%)	2 (3.6%)
Globe repair WRAMC	1 (6.3%)	0	1 (4.5%)	0	2 (1.2%)	0
Penetrating keratoplasty	3 (18.8%)	0	2 (9.1%)	0	16 (9.5%)	2 (3.6%)

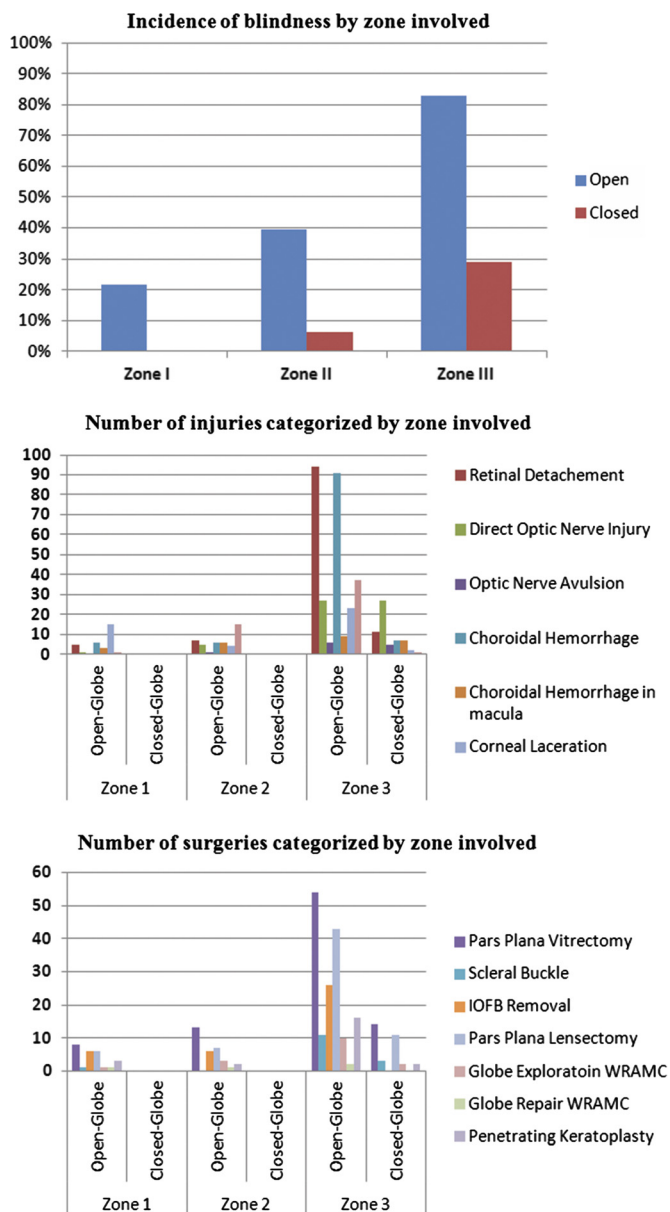


Figure 3. Injuries, surgeries, and rate of blindness categorized by zone.

compared with a odds ratio of 6.48 if the injury was an open-globe Zone II. There was also statistically significant difference in the surgeries performed base on the zone involved ($p < 0.01$). Most surgeries were performed in eyes with an open-globe Zone II injury, 0.966 surgeries per eye, followed by open-globe Zone I, with 0.924 surgeries per eye, and lastly open-globe Zone III eyes with 0.871 injuries per eye ($p < 0.01$). The most common mechanism of injury causing an open-globe injury was an improvised explosive device (IED) with 135 eyes (65.5%), followed by rocket-propelled grenade (RPG) with 26 eyes (12.6%). There were 22 penetrating injuries (10.7%), and an intraocular foreign body (IOFB) was present in 63 eyes (23.8%); 38 of the 63 underwent foreign body removal. Seventy-two eyes (35%) had perforating injuries, while globe rupture was

seen in 42 (20.4%). The average length of corneal/corneoscleral laceration was 5.60 ± 8.46 mm (range, 0–40 mm). Within the open-globe cohort, there were 106 retinal detachments (51.5%), 92 of which involved the macula, 103 choroidal hemorrhages (38.8%), 53 corneoscleral (20%) and 42 corneal lacerations (15.8%), 33 traumatic optic neuropathies (16%), 29 posterior sclera ruptures (14.1%), 22 choroidal ruptures (10.7%) with 16 involving the macula, 7 optic nerve avulsions (3.4%), and 1 case of postoperative endophthalmitis. One hundred eight eyes (40.8%) experiencing an open globe were enucleated, while 44 (16.6%) developed phthisis bulbi. The reported rate of eye protection use among the open-globe cohort was 37.1%. The most common surgery performed in the open-globe cohort was pars plana vitrectomy (75, 36.4%), followed by pars plana lensectomy (56, 27.2%), IOFB removal in addition to vitrectomy (38, 18.4%), and penetrating keratoplasty (21, 10.2%).

Of 108 enucleations in this sample, 61 (56.5%) were primary enucleations performed in the theater, while 5 were (1.9%) eviscerations performed in the theater. Secondary enucleations were performed in 36 eyes (33.3 %), and 6 enucleations (5.5 %) were performed after retinal detachment repair surgery during the follow-up interval. There were 50 retinal detachments (46.3%) in the entire enucleation cohort; however, 35 eyes had missing data and may have also had a retinal detachment, but limited documentation was available before enucleation. There were also 48 choroidal hemorrhages (44.4%), 33 involving the macula (30.6%). The use of eye protection in the enucleation cohort was documented in 35 patients (43.8%), whereas 17 patients (21.3%) had no documented eye protection, and 28 patients (35%) had missing data. The most common cause of injury leading to an enucleation was an IED (75, 69.4%), followed by gunshot wound (13, 12%) and an RPG (10, 9.25%). There were 41 eyes (48.2%) with no additional surgery beyond the primary enucleation, 38 eyes (35.2%) underwent one additional surgery, 8 eyes (7.4%) underwent two additional surgeries, 1 eye (0.9%) underwent three surgeries, and 1 eye (0.9%) underwent five additional surgeries.

Of the 56 closed-globe injuries, there were no Zone I injuries, one Zone II injury (1.8%), and 55 Zone III injuries

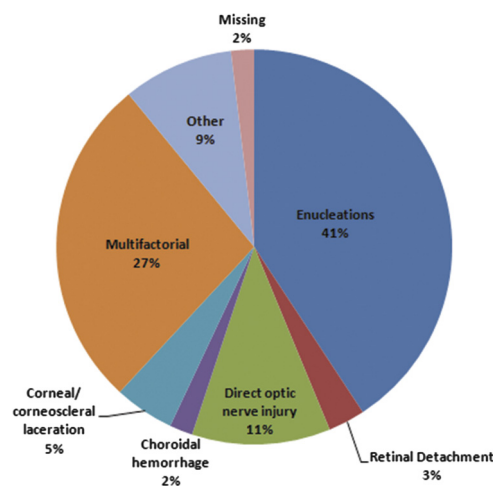


Figure 4. Major sources of blindness in combat ocular trauma.

(97.2%) (Table 2). The primary cause of closed-globe injury was an IED in 33 eyes (58.9 %), followed by gunshot-related injuries in 11 eyes (19.6%). The number of retinal detachments in the closed-globe group was 11 (19.6%), 7 of which included the macula, and 27 cases of traumatic optic neuropathy (48.2%), 7 choroidal hemorrhages (12.5%), 9 choroidal ruptures (16.1%), 2 partial-thickness corneal lacerations, and 1 partial-thickness corneoscleral laceration. The rate of eye protection use among the closed-globe cohort was 13 (28.9%), with 18 eyes (40%) missing data. The most common surgery in this group was pars plana vitrectomy (14, 25%), followed by pars plana lensectomy (11, 19.6%), and penetrating keratoplasty (2, 3.6%).

Neuroophthalmic injuries were divided into injuries of cranial nerves versus an injury to the brain, involving visual pathways and/or occipital cortex. Injuries to the optic nerve occurred at the time of initial trauma. Cranial nerves injuries occurred in 16 patients (6.0%). Cranial nerve III was affected in four eyes (1.5%), data for cranial nerve IV injuries were missing, cranial nerve V was affected in one eye (0.6%), and cranial nerve VII was injured in five eyes (3.1%). TBI was seen in 123 eyes (46.4 %); however, only 1 eye (0.4%) had a visual field defect associated with TBI; there were 39 skull fractures (14.7%).

DISCUSSION

The visual outcomes of combat ocular trauma have been widely studied. Since the beginning of OIF/OEF in 2001, several articles have focused on different types of injuries the soldiers have experienced.^{3–6,8} This review presents a subset analysis of soldiers with poor visual outcomes, defined as final BCVA of worse than 20/200, and describes the nature of the injuries in an attempt to elucidate the specific ocular injuries leading to blindness. Clearly, the nature of the combat injury played the most significant role, with IEDs frequently leading to severe and often irreparable ocular injuries.^{9,10} However, the specific anatomic cause of blindness is important to understand to better mitigate the impact of blindness on the war fighter population.

In this review, 41% of blind eyes sustained injuries that either were irreparable at the time of initial attempted repair necessitating enucleation or required semiurgent globe enucleation because of the risk of sympathetic ophthalmia in a severely traumatized and completely blind eye (Fig. 4). Data were incomplete for this category of eye injuries as many patients sustained injuries before the implementation of electronic health records. Furthermore, limited ophthalmic examinations were conducted in many of these cases because of the dynamic and highly pressured environment of multisystem injury or mass-casualty situations. The second leading etiology for blindness was multifactorial (27%), which encompassed eyes with a combination of potentially blinding ocular injuries, including corneal lacerations and resultant scarring, recurrent retinal detachment, and choroidal hemorrhages. Direct optic nerve injury was the third leading cause of the blindness, as seen in 11% of the eyes.

At the time of injury, 28.9% of blinded patients confirmed the use of eye protection. This highlights that despite use of polycarbonate eye protection, the eyes remain vulnerable to severe injury. The authors found a 25.1% rate of unrecorded eye protection use. Often, the injured service member cannot

recall whether eye protection was worn at the time of injury. Similarly, recording of eye protection is not the first responder's or the squad mate's first priority at the time of injury. As such, it is difficult to know the exact rate of eye protection use. However, this review demonstrated that at least one third of blinded eyes had eye protection. Despite this, countless other eyes were saved because of continued emphasis on wearing eye protection.¹⁰

There was a clear association between the zone of injury and long-term prognosis. An injury that occurred in Zone III led to more surgeries but often yielded disappointing visual results as compared with Zone I injuries, as outlined in Figure 3. As discussed earlier, eyes with open-globe Zone II injuries underwent a higher number of surgical procedures, followed by eyes with open-globe Zone I and open-globe Zone III. When this is compared with blindness based on the involved zone, open-globe Zone III had the highest incidence of blindness, which could mean that the surgeries performed on open-globe Zone II eyes led to visual recovery. Nevertheless, the eyes with final BCVA worse than 20/200 underwent more surgeries than the eyes with final BCVA of 20/200 or better, 0.961 surgeries per eye versus 0.436 surgeries per eye, respectively. Several conclusions could be drawn from this. One was that the more severe the injury, the more likely the eye would require one or more surgeries. Moreover, one may conclude that current surgical capabilities are limited to repair severely damaged eyes but can reconstitute vision in less severe injuries.

The limitations of this study include incomplete records and loss to follow-up. These contribute to missing some of the data from initial visit to the end of care at WRAMC. In addition, there was limited long-term tracking once the soldiers left the military health system. It is possible that more eyes eventually became blind and were excluded from this analysis because of limitations in follow-up. As such, the data in this study are skewed to the severest eye injuries at the earliest stages rather than chronic and progressive ocular diseases, such as traumatic glaucoma or progressive retinal degenerations.

Further research is needed to improve eye protection in an effort to prevent ocular injury and to develop strategies for improving visual outcomes in patient with combat ocular trauma.^{11,12}

AUTHORSHIP

A.V. was responsible for the study design, data analysis, interpretation and writing of the manuscript. A.V. takes responsibility for data integrity and accuracy. D.R. contributed to collecting, analyzing, interpreting the data and revising the manuscript. S.L. helped with data collecting, interpretation and revision of the manuscript. E.W. and M.C. were responsible for the study design, data collection, interpretation and revision of the manuscript.

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DISCLOSURE

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Open-globe wounds in operation Iraqi Freedom and Operation Enduring Freedom: risk factors for poor visual outcomes and enucleation

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ABSTRACT.

Purpose: To determine the rates and types of open-globe wounds in soldiers admitted to Walter Reed Army Medical Center from 2001 to 2011 after sustaining combat injuries.

Methods: Data were collected in the Walter Reed Ocular Trauma Database. Inclusion criteria were patients who suffered open-globe injuries. Open-globe injuries were classified by type of wound: corneal, corneo-scleral or scleral, or type of open-globe injury: perforating, rupture, penetrating or intraocular foreign body. The primary analysis assessed the effect on final visual acuity (VA) and the risk of enucleation.

Results: In this study, 285 (32.02%) open-globe injuries were recorded in 890 eyes in the data set. Corneal wounds were noted in 127 (44.56%) eyes, corneo-scleral wounds in 78 (27.37%) and scleral wounds in 129 (45.26%) eyes. The involvement of both the corneal and sclera was associated with poorer visual outcome (BCVA < 20/200) compared to injuries with an injury confined to either the cornea or sclera alone ($p = 0.038$). At a wound length of greater than approximately 14 mm, patients had 75% chance of having a poor final VA. Enucleation was performed in 64 (22.46%) eyes of patients with wounds. The type of wound was not found to be predictive of enucleation in multivariate analysis, but rather the type of open-globe injury was predictive. Perforating (OR: 1.58, 95% CI: 1.43–1.72) and globe rupture injuries (OR: 1.49, 95% CI: 1.33–1.66) were more likely to undergo enucleation.

Conclusions: Open-globe injuries occur frequently in combat ocular trauma. Poor final VA was noted most with corneo-scleral wounds with approximately 50% of patients having a final VA less than 20/200.

Key words: combat trauma – enucleation – eye injury – ocular trauma – open-globe injury

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Introduction

United States (US) Service members suffered a higher rate of ocular trauma during Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF) relative to previous wars (Stone 1950; Lowrey & Shaffer 1954; La Piana & Ward 1999). Of all US Servicemembers evacuated from OIF and OEF, 13% had major ocular trauma (Weichel & Colyer 2008). High velocity projectiles from improvised explosive devices (IEDs) and the advent of modern body armor led to higher rates of ocular trauma as the eyes became more exposed relative to the rest of the body (Weichel & Colyer 2008). Injury to the cornea and/or sclera are common and have been estimated to occur in up to 10% of all major ocular trauma (Hamill 2002). Previous publications of OEF and OIF have estimated that 15.8% of open-globe injuries (OGI) presented as corneal wound (Vlasov et al. 2015). In addition, due to the severity of eye injuries particularly in patients with wounds, the enucleation rate in modern warfare has ranged from 13% to 20% (Mader et al. 2006; Thach et al. 2008).

In this paper, the authors studied and characterized the eyes of all US service members evacuated to Walter Reed Army Medical Center

(WRAMC) from 2001 to 2011 with OGI during OIF and OEF. The goals were to characterize the rates of corneal, corneo-scleral or scleral wounds, and the effect on final visual acuity (VA) and the risk of enucleation.

Methods and Materials

Study design

The Walter Reed Ocular Trauma Database (WROTD) was a retrospective database of US Service members injured and evacuated to WRAMC between 2001 and 2011. It contains the data of patients evaluated by ophthalmologists in Iraq or Afghanistan at Combat Support Hospitals then treated, if necessary, at Landstuhl Regional Army Medical Center in Germany on route to WRAMC. Patients were then followed at WRAMC until they entered the Veterans Affairs medical system, returned to their unit, or had a permanent change of duty station. Patients were identified and included in this data set based on inpatient and outpatient records, transfer summaries and operative reports. The data were collected on Microsoft Excel (Microsoft Corporation, Redmond, WA, USA) and stored on SPSS (IBM, New York, NY, USA); R statistical software (R Foundation for Statistical Computing, Vienna, Austria) was then used for analysis. Further description of the collection of the data in the WROTD is outlined elsewhere (Weichel & Colyer 2008; Vlasov et al. 2015).

Inclusion criteria and outcomes

Inclusion criteria were any US Service-member or Department of Defense civilian injured in OIF/OEF with an OGI. Primary outcome measures were the effect of wound type: corneal, corneo-scleral and scleral on final VA, and the predictive risk factors for enucleation. Secondary outcome measures included the effect by length of wound and OGI injury type as defined by Birmingham Eye Trauma Terminology (BETT; Pieramici et al. 1997; Kuhn et al. 2002a; Kuhn et al. 2004) on final VA and enucleation.

Injury assessment

Corneal wounds were characterized by an injury of only the cornea, corneo-scleral wounds were a continuous injury of the

cornea, limbus and sclera, and scleral wounds involved only the sclera. Some eyes had multiple wounds depending on the mechanism of injury. For example, a perforating injury to an eye could have a corneal and scleral wound. For statistical analysis, increasing laceration length was studied as a continuous variable.

Snellen VA was converted to vision grades for statistical analysis (Vlasov et al. 2015). Grade 1 was defined as 20/40 or better, Grade 2 was 20/50 to 19/200, Grade 3 was 20/200 to 1/200 (count fingers), Grade 4 was hand motion or light perception and Grade 5 was no light perception. The patients' Ocular Trauma Scores (OTS) were calculated as described by Kuhn et al. (2002b).

Initial VA's were assessed when the patients were first able to complete VA testing. Due to the wartime trauma, patients frequently could not have their VA tested until after initial surgery and often not until they had arrived at WRAMC. For the entire dataset ($n = 890$), 57 were intubated and 44 eyes were missing data for initial VA. Per protocol, the postinjury VA was tested at the time range of 20–50 days postinjury, time range of 150–200 days postinjury and at the last documented VA date. Realistically, in many cases, only initial and final VA were obtained.

Statistical analysis

Univariate analysis was completed using Fisher's exact test for categorical variables and the Wilcoxon rank sum test with continuity correction for continuous variables. Multivariate analysis was completed using binomial logistic regression; significance was assessed using the Type 3 likelihood ratio test as implemented in the 'car' package. Both univariate and multivariate analyses discarded cases with missing information and analyzed records in which none of the variables tested in that analysis had missing values. Adjusted percentages reported with multivariate models and the associated confidence intervals were generated via estimated marginal means as implemented by the 'emmeans' package. Alpha was set at 0.05 for all analyses.

Results

Demographics

A total of 285 (32.02%) eyes out of 890 eyes in the data set had either single or

multiple open-globe wounds. The mean age of patients was 27.46 years (range: 18–53). Eye injuries in the study occurred predominantly in men ($N = 280$, 98.25%). Of the 285 injuries, 230 (80.70%) occurred in OIF (Iraq) and 55 (19.30%) in OEF (Afghanistan). The source of injury was recorded and 175 (61.40%) injuries were due to IED, 40 (14.04%) injuries from rocket-propelled grenade, 18 (6.31%) injuries from gunshot wounds, 14 (4.91%) injuries were from mines, 15 (5.26%) injuries were from mortar, 14 (4.91%) injuries from grenades and 9 (3.16%) injuries from other sources. Eye protection was used in 89 (31.23%) instances, not used in 94 (32.98%) instances and undocumented in 102 (35.79%).

Injuries and surgeries

Corneal wounds were noted in 127 (44.56%) eyes, corneo-scleral wounds in 78 (27.37%) and scleral wounds in 129 (45.26%) eyes. Regarding OGI types as classified in the BETT, 28 (9.82%) were globe ruptures, 49 (17.19%) were perforating, 132 (46.32%) were IOFBs, 49 (17.19%) were penetrating and 27 (9.47%) were unknown. The average wound length was 6.56 mm (range: approximately 0–40 mm) but was unknown in 81 (28.42%) patients. Enucleation was performed on 64 (22.46%) eyes.

Associated injuries are shown in Table 1. Corneal scars were found in 68 (23.86%) with band keratopathy developing in four (1.40%) eyes. While 141 (49.47%) injuries were unilateral, 126 (44.21%) were globe-globe, 17 (5.96%) were globe-adnexa and 1 (0.35%) was globe-neuro-ophthalmic. Zone 1 injuries occurred in 80 (28.07%) eyes, Zone 2 injuries in 53 (18.60%) and Zone 3 in 152 (53.33%) eyes.

In regards to surgeries, pars plana vitrectomy was performed in 152 (53.33%) of eyes and scleral buckle in 17 (5.97%) eyes. Pars plana lensectomy and cataract extraction with intraocular lens placement were performed in 95 (33.33%) and 51 (17.96%) instances. Penetrating keratoplasty was performed in 28 (9.83%) eyes.

Visual acuity and ocular trauma score

Initial and final VA data, and OTS are shown in Table 2. Of these, 13 (4.56%)

Table 1. Number and percentage of injuries associated with open-globe injury wounds.

Associated injury	Number	Percentage
Oculoplastic injuries	151	53.17
Retrobulbar haematoma	12	4.23
Lid injury	113	39.79
Orbital fracture	81	28.52
Orbital foreign body	62	21.83
Ptosis	4	1.41
Neuro-ophthalmic injuries	54	19.01
Direct optic nerve injuries	25	8.80
Optic nerve avulsion	3	1.06
Cranial nerve injury	7	2.46
Conjunctiva and cornea		
Conjunctival chemosis	16	5.63
Corneal abrasion	11	3.87
Corneal foreign body	49	17.25
Anterior segment		
Hyphaema	102	35.92
Iritis	8	2.82
Iris injury	117	41.20
Sphincter tear	13	4.58
Iridodialysis	57	20.07
Angle injury	49	17.25
Angle recession	7	2.46
Cyclodialysis cleft	4	1.41
Zonular dehiscence	27	9.51
Cataracts	164	57.75
Glaucoma	10	3.53
Posterior segment and retina		
Vitreous haemorrhage	204	71.83
Subretinal haemorrhage	88	30.99
Intraretinal haemorrhage	70	24.65
Macular haemorrhage	48	16.90
Comotio retinae	36	12.68
Comotio retinae involving the macula	32	11.27
Chorioretinal rupture (Sclopetaria Retinis)	29	10.21
Chorioretinal rupture involving the macula	20	7.04
Retinal tear	122	42.96
Retinal detachment	104	36.62
Choroidal haemorrhage	94	33.10
Choroidal haemorrhage involving the macula	59	20.77
Choroidal rupture	12	4.23
Choroidal rupture involving the macula	9	3.17
Phthisis	35	12.32
Associated systemic injuries		
Associated traumatic brain injury	101	35.56
Associated skull fracture	22	7.75
Associated face injury	163	57.39
Associated neck injury	13	4.58
Associated neurologic injury	62	21.83

had an unknown data, nine (3.17%) were initially intubated, 102 (35.79%) had no change in grade, 146 (51.23%) improved and 15 (5.26%) declined. In addition, 74 (25.9606%) had an afferent pupillary defect (APD).

Risk factors for final visual acuity and enucleation

Further univariate statistical analysis was performed to evaluate risk factors for enucleation and for final VA less than 20/200 (Table 3). An OTS of 0–65

was a very significant risk factor for poor final visual acuity (OR: 37.27, 95% CI: 17.90–82.64, $p < 0.0001$). For eyes that did not undergo enucleation, a regression analysis identified corneo-scleral wound ($p = 0.038$) and OGI type ($p < 0.0001$) as significant predictors of having a final VA less than 20/200, with marginal effects of scleral wound ($p = 0.055$) and little effect of corneal wound ($p = 0.33$). For non-enucleated eyes with a measured laceration length, wound length was a strong predictor of final visual acuity

(Table 4); the 50% inflection point of this binomial model was 8.98 mm. This model predicts that at 14.13 mm, patients had 75% chance of having a poor visual outcome with a final visual acuity less than 20/200, whereas at 3.84 mm, patients have only a 25% chance of having a poor visual outcome.

Univariate analysis of risk factors for enucleation was performed, and scleral laceration ($p < 0.001$) and increasing laceration length ($p < 0.001$) were found to be risk factors for enucleation (Table 3). In a multivariate model of enucleation based on type of OGI and wound, enucleation was strongly predicted by OGI type ($p < 0.0001$), with high adjusted rates of enucleation after perforating injuries (OR: 1.58, 95% CI: 1.43–1.71) and globe rupture injuries (OR: 1.49, 95% CI: 1.33–1.66), and low rates of enucleation after IOFB (OR: 1.10, 95% CI: 1.06–1.81) and penetrating injury (1.13, 95% CI: 1.06–1.28). Whether or not a patient had a corneal, corneo-scleral or scleral wound had little influence on enucleation ($p = 0.43$). For eyes with measured laceration lengths, laceration length was a predictor of enucleation likelihood, $p < 0.0001$. The 50% inflection point of this model, however, was 23.5 mm, with 25% and 75% likelihoods at 14.4 and 32.6 mm, respectively. Given that these laceration lengths are longer than most lengths in this dataset; more evidence at the upper end of the scale is needed to predict adverse outcomes in that range.

Discussion

In this retrospective case series, our goal was to determine the rates of corneal, corneo-scleral and scleral wounds in soldiers in OIF/OEF between 2001 and 2011 and determine if there was an association between the type and length of the wound, and final VA and eventual need for enucleation. Of all the eyes included in the WROTD, a total of 285 (32.02%) suffered wounds. The wounds were found to be divided into corneal wound in 44.56%, corneo-scleral wound in 27.37%, and scleral wound in 45.26%. Compared to a previous study, our rates of corneal and corneo-scleral wounds were similar, but

Table 2. A. Ocular trauma score. B. Visual Acuity (VA). Grade 1 was 20/40 or better, Grade 2 was 20/50 to 19/200, Grade 3 was 20/200 to 1/200 (count fingers), Grade 4 was hand motion or light perception and Grade 5 was no light perception.

A					
OTS grade	#		%		
Grade 1 (0-44)	65		22.89		
Grade 2 (45-65)	80		28.17		
Grade 3 (66-80)	82		28.87		
Grade 4 (81-90)	13		4.58		
Grade 5 (91-100)	27		9.51		
Unknown	17		5.99		

B					
Initial VA grade	#	%	Final VA grade	#	%
Grade 1	28	9.86	Grade 1	101	35.56
Grade 2	15	5.28	Grade 2	34	11.97
Grade 3	25	8.80	Grade 3	18	6.34
Grade 4	118	41.55	Grade 4	41	14.44
Grade 5	81	28.52	Grade 5	85	29.93
Unknown	17	5.99	Unknown	5	1.76

there were higher rates of scleral wound (Sheng et al. 2015).

Generally, visual prognosis after OGI is poor with 14.4–62.8% having a VA better than 20/200 (Bauza et al. 2013a; Sheng et al. 2015). In univariate analysis, we found a positive association between suffering a scleral or corneo-scleral wound and having a final VA less than 20/200. We found a negative association between suffering a corneal wound and having a final VA less than 20/200. Thus, patients that suffered a corneal laceration were less likely to have a poor final visual outcome. This is likely due to lower severity of these injuries compared to sclera or corneo-scleral injury. But in multivariate analysis, for eyes that did not undergo an enucleation and had an OGI, corneo-scleral wound ($p = 0.038$) was predictive of a poor final VA.

An enucleation rate of between 4.44% and 31.1% in patients suffering corneal and/or scleral wounds has been previously noted (Bauza et al. 2013a; Bauza et al. 2013b; Sheng et al. 2015). In univariate analysis, we also found a positive association between suffering a scleral wound and eventually undergoing enucleation (Table 3). In multivariate analysis, the type of globe injury was a stronger predictor than wound type; specifically, perforating and rupture injuries were predictors of enucleation. This is like the results to other

studies that have demonstrated that patients with perforating or rupture injuries were more likely to have a final VA of NLP and an enucleation, while those with a penetrating injury were less likely (Savar et al. 2009; Bauza et al. 2013a; Bauza et al. 2013b).

Previous studies on open-globe injuries have found that wound length is a strong predictor of poor final visual acuity (Barr 1983; Han & Yu 2010; Agrawal et al. 2011). In our study, wounds longer than 10 mm had a higher percentage of poor final visual outcome; more specifically at 14.13 mm, patients had 75% chance of having a poor visual outcome with a final visual acuity less than 20/200 (Table 4). This is an important prognostic indicator that can aid in counselling of the family.

There were multiple limitations to this study. Primarily, there was relatively poor longitudinal patient data tracking from the point of injury to WRAMC. Analysis of the data was complicated by incomplete records, difficulty in long-term tracking of soldiers once they left WRAMC, and impediments documenting initial VA making OTS and initial VA outcomes troublesome to assess. Particularly, approximately one third of the eye protection use data is missing making it difficult to assess the effect of eye protection on the severity of the injury.

In conclusion, approximately 50% of patients with a wound injury had a

Table 4. Wound length effect on final visual acuity (VA).

Wound length (mm)	VA > 20/200 (%)	VA < 20/200 (%)
0–2	84.21	15.79
2–5	84.91	15.09
5–10	60.98	39.02
>10	15.38	84.62

Table 3. Univariate analysis of risk factors for enucleation and final visual acuity (VA).

Enucleation	OR	95% CI	p-value	Final VA < 20/200	OR	95% CI	p-value
Hyphaema	1.11	0.58–2.09	0.76	Hyphaema	3.07	1.78–5.37	<0.001
Vitreous haemorrhage	1.95	0.91–4.61	0.09	Vitreous haemorrhage	2.81	1.54–5.24	<0.001
Lens injury	2.00	0.957–4.53	0.055	Lens Injury	3.68	2.02–6.87	<0.001
Increasing laceration length	1.13	1.08–1.20	<0.001	Increasing laceration length	1.24	1.16–1.35	<0.001
Corneal laceration	0.19	0.08–0.38	<0.001	Corneal laceration	0.24	0.14–0.41	<0.001
Corneo-scleral laceration	1.83	0.96–3.43	0.06	Corneo-scleral Laceration	2.69	1.49–4.98	<0.001
Scleral laceration	3.47	1.86–6.68	<0.001	Scleral laceration	3.44	2.04–5.87	<0.001
Zone 1 versus Zone 2	0.155	0.011–2.21	0.23	Zone 1 versus Zone 2	.377	0.145–0.981	0.04
Zone 1 versus Zone 3	0.020	0.002–0.218	0.0004	Zone 1 versus Zone 3	.082	0.037–0.182	<0.0001
Zone 2 versus Zone 3	0.129	0.036–0.463	0.0005	Zone 2 versus Zone 3	.217	0.097–0.489	<0.0001

final visual acuity less than 20/200. This study found that for patients with an OGI that a corneo-scleral wound ($p = 0.038$) was predictive of a poor visual outcome less than 20/200 compared to scleral and corneal wounds. Enucleation was performed in about 25% of patients with open-globe injury wounds. The type of wound was not found to be predictive of enucleation in multivariate analysis, but perforating injuries (OR: 1.58, 95% CI: 1.43–1.72) and globe rupture injuries (OR 1.49, 95% CI: 1.33–1.66) were predicative of enucleation.

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Institutional Review Board approval at Walter Reed National Military Medical Center was obtained. The study adhered to the Declaration of Helsinki. Informed consent was not completed as a HIPAA waiver was granted due to deidentified collection.



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Intraocular Foreign Body Trauma in Operation Iraqi Freedom and Operation Enduring Freedom

2001 to 2011

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Purpose: We update the incidence of intraocular foreign bodies (IOFB) in soldiers admitted to Walter Reed Army Medical Center from 2001 to 2011 after sustaining combat injuries in Operation Iraqi Freedom and Operation Enduring Freedom.

Design: This consecutive retrospective case series included 890 eyes of 652 patients.

Methods: Data were collected in the Walter Reed Ocular Trauma Database. Inclusion criteria were any American soldier or Department of Defense civilian with an IOFB injured in Operation Iraqi Freedom/Operation Enduring Freedom. Closed globe injuries with orbital foreign bodies, injury outside of a combat zone, or non-Department of Defense civilian trauma were the exclusion criteria.

Main Outcome Measures: Primary outcome measures were final visual outcome and the number, size, and location of IOFBs. Secondary outcome measures included surgical procedures, use of eye protection, associated complications, source of injury and Ocular Trauma Score.

Results: There were 890 eye injuries in 652 patients evacuated to Walter Reed Army Medical Center between 2001 and 2011. IOFBs were found in 166 eyes of 149 patients (18.6%; 95% confidence interval [CI], 16.2%–21.3%). Most patients had a single IOFB (80.7%). An IOFB was positively associated with Ocular Trauma Score grade 1 or 2 (0–65) injuries (odds ratio [OR], 1.58; 95% CI, 1.07–2.38; $P = 0.01$). There were 130 eyes (78.33%) that had recorded time from initial visual acuity to final visual acuity and it ranged from 8 to 2421 days (mean, 433.24 days). Thirty-eight (25.16%; 95% CI, 18.89%–32.67%) eyes had no change in visual acuity, 98 (64.90%; 95% CI, 57.00%–72.07%) had improved visual acuity, and 15 (9.93%; 95% CI, 6.01%–15.84%) had decreased visual acuity. IOFB was not found to predict final visual acuity of $<20/200$ in multivariate analysis when other injury features were known ($P = 0.1$). Pars plana vitrectomy was completed on 124 eyes (74.70%). Removal of IOFB was performed in 118 eyes (71.08%; average of 31.67 days after initial injury) with a delayed procedure occurring after primary closure and antibiotics owing to a lack of surgical capacity in Iraq and Afghanistan. Retinal detachment occurred in 48 eyes (28.92%) and proliferative vitreoretinopathy in 44 eyes (26.5%).

Conclusions: IOFBs occur frequently in combat ocular trauma and are significantly associated with more severe injuries. However, IOFBs were not found to be a significant risk factor for visual acuity of $<20/200$. *Ophthalmology* 2018;■:1–8 Published by Elsevier on behalf of the American Academy of Ophthalmology

Combat ocular injuries have increased steadily in wars involving American Soldiers from 0.5% during the American Civil War,¹ approximately 2.0% during World Wars I and II,^{2,3} and currently 13% in Operation Iraqi Freedom/Operation Enduring Freedom (OIF/OEF).⁴ The dramatic increase is likely owing to the use of body armor that protects the abdomen and pelvis but leaves the head, neck, and extremities exposed, as well as improvised explosive devices (IED) that cause a mixture of blast, penetrating, and burn trauma. Intraocular foreign body (IOFB) injuries commonly occur within the setting of deployment to a

combat zone. Previously, the rate of IOFB trauma reported in OIF/OEF in patients with eye trauma ranged from 14.6% to 16.4%.^{4,5} Traditionally, IOFB injuries are considered an ophthalmic urgency with removal planned at the time of primary globe repair or shortly thereafter. Colyer et al⁶ previously reported the absence of IOFB-associated endophthalmitis in a nonurgent extraction situation necessitated by wartime geographical constraints. In this article, we review all soldiers with IOFBs evacuated from Iraq and Afghanistan to Walter Reed Army Medical Center (WRAMC) from 2001 to 2011.

Materials and Methods

The Walter Reed Ocular Trauma Database (WROTD) is a retrospective case series of 890 eyes of 652 American OIF/OEF service members injured and evacuated to WRAMC between 2001 and 2011. Institutional Review Board approval at Walter Reed National Military Medical Center was obtained. WROTD contains the data of the initial care of soldiers who were evaluated by ophthalmologists in Iraq or Afghanistan at combat support hospitals then treated, if necessary, at Landstuhl Regional Army Medical Center in Germany en route to WRAMC. The majority of trauma patients, regardless of physical location of injury in OIF/OEF, were initially evacuated to WRAMC, although some were sent to other large military medical centers in the United States. Patients were then followed at WRAMC until they entered the Veterans Affairs medical system, returned to their unit, or had a permanent change of duty station. Patients were identified and included in this dataset based on inpatient and outpatient records, transfer summaries, and operative reports. More than 150 variables per patient were collected when available including age, gender, all intraocular, orbital and peri-orbital injuries; associated injuries; initial and final visual acuity (VA); Ocular Trauma Score (OTS); and duration of follow-up. The data were collected on Microsoft Excel (Microsoft Corporation, Redmond, WA) and stored on SPSS (IBM, New York); R statistical software (R Foundation for Statistical Computing, Vienna, Austria) was then used for analysis. Further description of the collection of the data in the WROTD is outlined elsewhere.^{4,7}

Inclusion criteria were any American Soldier or Department of Defense civilian injured in OIF/OEF with an IOFB. Exclusion criteria included isolated closed globe injuries with corneal, conjunctival or orbital foreign bodies, injury outside of a combat zone, or non-Department of Defense civilian trauma. Primary outcome measures were final VA and the number, size, and location of IOFBs. Secondary outcome measures included surgical procedures performed; use of eye protection; associated eye injuries including cataract, phthisis bulbi, retinal detachment, and proliferative vitreoretinopathy (PVR); source of injury; and OTS.

Injuries were classified as described by Birmingham Eye Trauma Terminology.⁸⁻¹⁰ Snellen VAs were converted to vision grades for statistical analysis.^{4,11} Grade 1 was defined as $\geq 20/40$; grade 2 was defined as 20/50 to 19/200; grade 3 was defined as 20/200 to 1/200 (count fingers); grade 4 was defined as hand motion or light perception; and grade 5 was defined as no light perception. The patients' OTS were calculated as described by Kuhn et al.¹² The OTS were calculated from initial documentation at time of injury.

Initial VAs were assessed when the patients were first initially awake. Owing to the wartime trauma, patients frequently could not have their VAs tested until after initial surgery and often not until they had arrived at WRAMC. For the entire dataset ($n = 890$), 99 patients did not have recorded initial VAs and of these 55 were initially intubated. Per protocol, the postinjury VA was tested at the time range of 20 to 50 days postinjury, at a time range of 150 to 200 days postinjury, and at the last documented VA date. In some cases, only initial and final VAs were recorded into the database owing, in part, to a lack of access to paper records and/or inpatient electronic records.

Statistical Analysis

Univariate analysis was completed using Fisher's exact test for categorical variables and the Wilcoxon rank-sum test with continuity correction for continuous variables. Odds ratios (ORs) and 95% confidence intervals (CIs) given for categorical variables were also computed via Fisher's method. For proportions and incidence rates, the Agresti and Coull method¹³ was used to calculate the CIs.

Multivariate analysis was completed using binomial logistic regression; significance was assessed using the type 3 likelihood ratio test as implemented in the "car" package.¹⁴ Post hoc tests of individual parameters were conducted using the R package emmeans.¹⁵ Univariate and multivariate analyses discarded cases with missing information and analyzed records in which none of the variables tested in that analysis had missing values; proportions and incidence rates counted the total number of positive incidences over the total number of eyes in the set. Alpha was set at 0.05 for all analyses.

Results

Demographics

There were 890 eye injuries in 652 patients evacuated to WRAMC between 2001 and 2011. The IOFBs were positively diagnosed in 166 eyes of 149 patients (18.65%; 95% CI, 16.23%–21.35%). The characteristics of IOFB injuries in the WROTD are presented in Table 1. The median age of the patients was 24 years (range, 18–52 years). There were 146 male patients (97.99%) and 3 female (2.01%). IOFB injuries were sustained between 2002 and 2011. Overall, 133 injuries (80.12%) occurred in Iraq and 33 (19.88%) occurred in Afghanistan. Most IOFBs occurred owing to IEDs (101 [60.84%]), with other injuries caused by rocket-propelled grenades (24 [14.46%]), mortar (12 [7.23%]), mines (10 [6.02%]), grenades (9 [5.42%]), gunshot wounds (7 [4.22%]), and other causes (3 [1.81%]). Eye protection was not worn in 63 cases (37.95%), worn in 49 cases (29.52%), and undocumented in 54 cases (32.53%).

VA and OTS

The OTS grades, initial VAs, and final VAs are summarized in Table 2. The initial VA was unavailable for 13 eyes (7.83%), OTS grade was unavailable for 13 eyes (7.83%), and final VA was unavailable for 3 eyes (1.80%). The time from initial VA to final

Table 1. IOFB Data: Number, Size, Volume, and Location

	n	%
No. of IOFB per eye		
1	134	80.70
2	10	6.02
3	15	9.04
4	3	1.81
6	2	1.20
10	2	1.20
	Average	Range
Size of IOFB (mm)	3.55	0.5–84
Volume of IOFB (mm ³)	25.04	0.25–600
Final location of IOFB	N	%
Lens	1	0.60
Vitreous	45	27.11
Retina	29	17.47
Subretinal space	9	5.42
Choroid	4	2.41
Sclera	7	4.22
Perforated sclera	20	12.05
Anterior chamber	4	2.41
Unknown	18	10.84
N/A	29	17.47

IOFB = intraocular foreign bodies.

Table 2. OTS, Initial VA, and Final VA Grades

OTS	n	%	Initial VA	n	%	Final VA	n	%
Grade 1 (0–44)	18	10.84	Grade 1	20	12.05	Grade 1	66	39.76
Grade 2 (45–65)	47	28.31	Grade 2	11	6.63	Grade 2	28	16.87
Grade 3 (66–80)	60	36.14	Grade 3	17	10.24	Grade 3	15	9.04
Grade 4 (81–90)	9	5.42	Grade 4	79	47.59	Grade 4	17	10.24
Grade 5 (91–100)	19	11.45	Grade 5	26	15.66	Grade 5	37	22.29

OTS = Ocular Trauma Score; VA = visual acuity.

Grade 1 was $\geq 20/40$; grade 2, 20/50–20/200; grade 3, 19/200–1/200 (count fingers); grade 4, hand motion or light perception; grade 5, was no light perception.

VA was available in 130 eyes (78.33%) and ranged from 8 to 2421 days (mean, 433.24 days). Regarding change in VA from initial VA to last documented VA, 15 eyes had missing initial or final data, with 5 of these eyes in patients who were initially intubated and therefore unevaluated; of the remaining 151 cases, 38 had no change (25.16%; 95% CI, 18.89%–32.67%), 98 had improved VA (64.90%; 95% CI, 57.00%–72.07%), and 15 had decreased VA (9.93%; 95% CI, 6.01%–15.84%). There was 1 death during follow-up. An afferent pupillary defect was noted in 40 eyes (24.10%; 95% CI, 18.20%–31.17%).

Zone of Injury

Zone 1 injuries occurred in 58 eyes (34.94%; 95% CI, 28.09%–42.47%), zone 2 injuries occurred in 37 eyes (22.29%; 95% CI, 16.59%–29.24%), and zone 3 injuries occurred in 71 eyes (42.77%; 95% CI, 35.49%–50.38%). Seventy-seven injuries (46.39%; 95% CI, 38.97%–53.97%) occurred in patients who had a unilateral injury, 82 injuries (49.40%; 95% CI, 41.89%–56.93%) occurred in patients who had bilateral globe injuries, 6 injuries (3.61%; 95% CI, 1.49%–7.83%) occurred in patients who had a bilateral globe-adnexal injury, and 1 injury (0.60%; 95% CI, 0%–3.67%) occurred in a patient who had a bilateral globe-neurologic injury.

Associated Injuries

Associated injuries were recorded (Table 3). In addition, later complications were also monitored. Phthisis occurred in 21 eyes (12.65%; 95% CI, 8.36%–18.63%). There was 1 case of post-pars plana vitrectomy (PPV) endophthalmitis (0.60%; 95% CI, 0%–3.67%). PVR occurred in 44 eyes (26.51%; 95% CI, 20.58%–33.72%). Corneal scars were found in 50 eyes (30.12%; 95% CI, 23.64%–37.50%), and 4 cases (2.41%; 95% CI, 0.73%–6.24%) of band keratopathy occurred. Finally, associated head and neck injuries were recorded. Facial injury was found in 95 (57.23%; 95% CI, 49.62%–64.51%), neurologic injury in 21 (12.65%; 95% CI, 8.36%–18.63%), and neck injury in 8 (4.82%; 95% CI, 2.31%–9.37%). Skull fractures were found in 7 (2.41%; 95% CI, 0.73%–6.24%). Traumatic brain injury (TBI) was found in 46 (27.71%; 95% CI, 21.45%–34.98%).

Surgeries

PPV was the most common surgery and was performed in 124 eyes (74.7%; 95% CI, 67.56%–80.73%). IOFB removal was completed in 118 eyes (71.08%; 95% CI, 63.76%–77.46%). Of these cases, 57 had a known day of removal with an average of 31.67 days after injury and a range of removal from date of injury to 600 days after initial injury. Other surgeries included pars plana lensectomy in 78 (46.99%; 95% CI, 39.55%–54.56%), cataract extraction with posterior chamber intraocular lens placement in 43 (25.9%; 95% CI, 19.82%–33.08%), penetrating keratoplasty in 21 (12.65%; 95% CI, 8.36%–18.63%), enucleation in 20 (12.05%; 95% CI, 7.86%–17.95%), scleral buckle in 10 (6.02%; 95% CI, 3.18%–10.86%), and fracture repair in 4 (2.41%; 95% CI, 0.73%–6.24%).

CI, 19.82%–33.08%), penetrating keratoplasty in 21 (12.65%; 95% CI, 8.36%–18.63%), enucleation in 20 (12.05%; 95% CI, 7.86%–17.95%), scleral buckle in 10 (6.02%; 95% CI, 3.18%–10.86%), and fracture repair in 4 (2.41%; 95% CI, 0.73%–6.24%).

Univariate and Multivariate Analyses

A univariate analysis of select variables was completed to identify features that were different in eyes with an IOFB versus those that did not have an IOFB (Table 4). Although 31.63% of patients without an IOFB had OTS grade 1 or 2 injuries, 42.5% of patients with an IOFB had OTS grade 1 or 2 injuries; therefore, IOFB was positively associated with OTS grade 1 or 2 injuries (OR, 1.60; 95% CI, 1.08–2.35; $P = 0.01$). Critically, patients had significantly higher risk of cataract (OR, 17.10; 95% CI, 11.17–26.55; $P < 0.001$) with associated increased odds of both pars plana lensectomy (OR, 14.82; 95% CI, 9.36–23.78; $P < 0.001$) and cataract extraction with posterior chamber intraocular lens placement (OR, 10.15; 95% CI, 5.78–18.21; $P < 0.001$). In addition, patients were at a greater risk for developing postoperative PVR (OR, 7.55; 95% CI, 4.48–12.85; $P < 0.001$) and phthisis (OR, 4.22; 95% CI, 2.16–8.22; $P < 0.001$). Contrastingly, an IOFB was negatively associated with TBI (OR, 0.51; 95% CI, 0.34–0.75; $P < 0.001$).

To ascertain the importance of IOFB relative to other risk factors, a multivariate analysis was completed on all nonenucleated eyes in the WROTD (Table 5). This logistic regression predicted whether patients had a final VA of grades 1 or 2 ($\geq 20/200$ vision) or grades 3 to 5 (count fingers, light perception/hand motions, no light perception) from 6 features: IOFB, retinal detachment, perforating injury, globe rupture, optic nerve injury, and phthisis. For this analysis, retinal detachment, globe rupture, and perforating injury were included because they are components of the OTS. Optic nerve injury was selected instead of APD (fourth component of the OTS), as at times the APD that was recorded in the WROTD may have been completed by a nonophthalmologist. Endophthalmitis, the last component of the OTS, was not included because it was very rare in the WROTD. Phthisis was included because it is owing to severe trauma and is a cause of blindness. Here, the IOFB was not found to be a statistically significant predictor of final VA ($P = 0.1$) when accounting for the other predictors, which each significantly predicted final VA (all $P < 0.001$).

In addition, another univariate analysis was completed on patients injured with an IOFB of those who developed PVR post-vitrectomy versus those who did not develop PVR (Table 6). Certain IOFB characteristics were evaluated: duration of time to removal ($P = 0.11$), total number of IOFBs ($P = 0.97$), and volume of the largest IOFB per eye ($P = 0.02$). Having an OTS grade 1 or 2 (0–65) injury (OR, 0.2; 95% CI, 0.08–0.47; $P < 0.001$), retinal detachment (OR, 4.89; 95% CI, 2.15–11.38;

Table 3. Associated Injuries

	n	%	95% CI
Occuloplastic			
Orbital foreign body	35	21.08	15.54–27.94
Orbital fracture	38	22.89	17.13–29.88
Neuroophthalmic			
Direct optic nerve injury	11	6.63	3.62–11.59
Optic nerve avulsion	1	0.60	0–3.67
Cranial nerve injury	4	2.41	0.73–6.24
Anterior segment			
Cornea and conjunctiva			
Conjunctival chemosis	11	6.63	3.62–11.59
Corneal abrasion	8	4.82	2.31–9.37
Corneal laceration	73	43.98	36.64–51.58
Corneal foreign body	31	18.67	13.44–25.33
Corneoscleral laceration	34	20.48	15.01–27.29
Scleral laceration	58	34.94	28.09–42.47
Anterior chamber			
Hyphema	60	36.14	29.22–43.7
Iritis	5	3.01	1.1–7.05
Iris injury	55	33.13	26.41–40.61
Sphincter tear	6	3.61	1.49–7.83
Iridodialysis	33	19.88	14.48–26.64
Angle injury	19	11.45	7.38–17.26
Zonular dehiscence	8	4.82	2.31–9.37
Traumatic cataract	114	66.67	61.25–75.25
Glaucoma	6	3.61	1.49–7.83
Retina and posterior segment			
Globe rupture	5	3.01	1.1–7.05
Posterior orbital rupture	4	2.41	0.73–6.24
Vitreous hemorrhage	122	73.49	66.28–79.64
Vitreous avulsion	2	1.20	0.05–4.57
Retinal hemorrhage			
Subretinal hemorrhage	58	34.94	28.09–42.47
Intraretinal hemorrhage	45	27.11	20.9–34.35
Macular hemorrhage	33	19.88	14.48–26.64
Traumatic retinal tear	73	43.98	36.64–51.58
Traumatic retinal detachment	48	28.92	22.54–36.24
Macula-on retinal detachment	19	11.45	7.38–17.26
Macula-off retinal detachment	27	16.27	11.38–22.68
Comotio retinae	28	16.87	11.89–23.35
Comotio retinae involving the macula	25	15.06	10.36–21.34
Chorioretinal rupture (sclopetaria retinis)	19	11.45	7.38–17.26
Chorioretinal rupture involving the macula	11	6.63	3.62–11.59
Choroidal hemorrhage	38	22.89	17.13–29.88
Choroidal hemorrhage involving the macula	23	13.86	9.35–19.99
Choroidal rupture	5	3.01	1.1–7.05
Choroidal rupture involving the macula	4	2.41	0.73–6.24
Choroidal and retinal vascular injury	4	2.41	0.73–6.24

CI = confidence interval.

$P < 0.001$), subretinal hemorrhage (OR, 3.38; 95% CI, 1.53–7.63; $P = 0.001$), macular hemorrhage (OR, 3.84; 95% CI, 1.57–9.45; $P = 0.001$), and zone of injury ($P = 0.002$) were all found to be significant variables.

Discussion

IOFBs have been commonly associated with ophthalmologic trauma in OIF and OEF. As reported, IOFB occurred in 14.6% to 16.4%^{4,5} of eye injuries and, in the current

Table 4. Associated Injuries, Surgeries, OTS Grades, and Final VA in Patients with IOFB Versus Those Without IOFB

Variables	OR	95% CI	P Value
Cataract	17.10	11.17–26.55	<0.001
PPL	14.82	9.36–23.78	<0.001
CEPCIOL	10.15	5.78–18.20	<0.001
PVR	7.55	4.48–12.85	<0.001
Retinal tear	4.64	3.14–6.87	<0.001
Phthisis	4.22	2.16–8.22	<0.001
Hyphema	3.29	2.20–4.90	<0.001
RD	2.67	1.74–4.05	<0.001
Final VA grade 3–5	1.87	1.29–2.72	<0.001
OTS grade 1–2 (0–65)	1.58	1.07–2.38	0.01
TBI	0.51	0.34–0.75	<0.001
ON	0.36	0.32–1.37	0.36 (NS)
Enucleation	1.25	0.70–2.17	0.39 (NS)

CEPCIOL = cataract extraction with posterior capsule intraocular lens placement; CI = confidence interval; IOFB = intraocular foreign body; NS = not significant; ON = optic nerve injury; OR = odds ratio; OTS = Ocular Trauma Score; PPL = pars plana lensectomy; PVR = proliferative vitreoretinopathy; RD = retinal detachment; TBI = traumatic brain injury; VA = visual acuity.

study, 18.65% (95% CI, 16.22%–21.34%) of the WROTD eye injuries had an IOFB. In a recent study¹¹ using the WROTD, IOFB occurred in 63 eyes (23.8%) with a final best-corrected VA of <20/200. In 2008, Weichel et al⁴ found that, in eyes with a final best-corrected VA of <20/200, the OR of a concurrent IOFB was 1.2 (95% CI, 0.7–0.21; $P = 0.49$). In our study, although about 73.49% of presenting eyes had an initial VA grade of 3, 4, or 5 or <20/200, 41.57% of eyes had a final VA of grade 3, 4, or 5. IOFB was not found to be a significant risk factor for grade 3, 4, or 5 final VA ($P = 0.10$) when accounting for other predictors of poor visual outcome.

IOFB and associated use of eye protection was reviewed, and more patients with IOFBs were found to not have worn eye protection. Although wraparound, polycarbonate lenses that can stop the force of a 0.22-caliber bullet from 20 feet have been developed,¹⁶ there were still patients (29.52%) who had an IOFB and wore eye protection. This finding does not diminish the importance of wearing eye protection but demonstrates that eyes remain vulnerable to penetrating or IOFB injury. Further research is necessary to ensure better eye protection as service members

Table 5. Analysis of Risk Factors for Final VA of <20/200

Variable	P Value	OR	95% CI
IOFB	0.10	1.67	0.91–3.05
ON	<0.001	28.92	14.10–59.33
RD	<0.001	6.99	3.44–14.20
Phthisis	<0.001	71.05	8.74–577.71
Rupture	<0.001	24.61	2.50–242.25
Perforating	<0.001	9.95	2.67–37.02

CI = confidence interval; IOFB = intraocular foreign body; ON = optic nerve injury; OR = odds ratio; RD = retinal detachment; VA = visual acuity.

Table 6. Univariate Analysis of Associated Injuries, OTS Grade, and IOFB Characteristics in the Occurrence of PVR in Patients with IOFB

Variables	P Value	OR	95% CI
OTS grade 1–2 (0–65)	<0.001	0.20	0.08–0.47
Vitreous hemorrhage	0.08	2.54	0.88–9.05
Hyphema	0.06	2.04	0.92–4.49
Intraretinal hemorrhage	0.04	2.21	0.97–5.02
Retinal tear	0.04	2.20	1.01–4.93
Subretinal hemorrhage	0.001	3.38	1.53–7.63
Macular hemorrhage	0.001	3.84	1.57–9.45
RD	<0.001	4.89	2.15–11.38
Zone of injury	0.001		
IOFB (total N)	0.97		
IOFB removal (d)	0.11		
IOFB volume (largest)	0.02		
IOFB depth of penetration	<0.001		
Age	0.15		

CI = confidence interval; IOFB = intraocular foreign body; OR = odds ratio; OTS = Ocular Trauma Score; PVR = proliferative vitreoretinopathy; RD = retinal detachment.

anecdotally complain that the current eye protection gets foggy or dirty, or otherwise obstructs their ability to do their job effectively. Critically, a recent study¹⁷ looking at 3276 patients in the Joint Theater Trauma Registry found a significant difference in the rate of ocular injury in patients wearing and not wearing eye protection (17% vs 26%, respectively; $P < 0.01$). Another study¹⁸ compared International Security Assistance Force and Afghan National Security Force, and the number in each group/eye protection use was 41/40 and 53/0, respectively. As expected, there was a significant difference in eye injury, bilateral injury, corneal abrasion, globe penetration, and eyelid laceration between the International Security Assistance Force and the Afghan National Security Force. Our study showed that in 32.53% of patients it was undocumented whether they had been wearing their eye protection. Information was not available owing to amnesia from traumatic brain injuries sustained at the time of injury, lack of documentation by primary responders, or absence of witnesses to the injury at the combat support hospitals. Also, use of eye protection may be overstated owing to concern for repercussion by the service member for admitting that they were not wearing eye protection. For example, they may have reported “yes” if the glasses/goggles were on their helmet rather than on their face.

One of the interesting observations of this study was that IOFB was negatively associated with TBI (OR, 0.51; 95% CI, 0.34–0.75; $P < 0.001$) and no significant association was found with optic nerve injuries (OR, 0.36; 95% CI, 0.32–1.37; $P = 0.36$). In addition, only 6 IOFBs (3.61%) occurred in patients who had a bilateral globe-adnexal injury and 1 (0.60%) in a patient who had a bilateral globe-neurologic injury. It seems that IOFB injuries are less often associated with adnexal or neurologic injuries, but rather solely eye injuries. This pattern demonstrates that more frequent use of eye protection could decrease the

number of IOFB injuries and its associated injuries, thus decreasing the total number of combat eye injuries and improving long-term morbidity. In addition, it may be that patients with IOFBs are further from the site of IED explosion, making their initial injuries less severe as demonstrated by a negative association with TBI and that most patients have OTS grade of 3 to 5 (66–100) injuries.

Endophthalmitis occurs after open-globe injury in approximately 1 in 100 cases^{19,20} but can range in incidence from 0% to 16.5%.^{6,21–26} No eyes had posttraumatic endophthalmitis, despite IOFB removal on average at 31.67 days after injury. However, in our study of 166 eyes, 1 eye developed postoperative endophthalmitis after PPV and IOFB removal. Postoperative endophthalmitis is significantly rarer, occurring in 0.025% to 0.09% of cases.^{27,28} Our patient was a 20-year-old soldier injured in 2004 with a zone 1, 5-mm IOFB penetrating to the retina with a retinal tear. He was not wearing eye protection. The patient was found to have an OTS grade 2 with an initial VA grade of 2. He was lost to follow-up at <6 months, but at his last visit was found to have a final VA grade of 3. He received a pars plana vitrectomy at Landstuhl Regional Army Medical Center. In addition, he underwent an IOFB removal. Although the date of the IOFB removal was unknown, it likely occurred in conjunction to the PPV. This patient was treated before arrival at WRAMC and at that time he had no signs of infection. Surgical reports are unavailable. There were no cases of preoperative endophthalmitis. Ahmed et al¹⁹ found that risk factors for endophthalmitis included retained IOFB, delay in wound closure of >24 hours, injury in a rural setting, and ruptured lens capsule. Disruption of the lens capsule can increase the risk of infection because the lens capsule can be a source of nutrition for the microorganism and there is disruption of flow of the aqueous.^{19,29} The lack of clear data related to this case was a common issue early in OIF/OEF, before the advent of an electronic health record.

There is considerable debate in the literature regarding delayed versus immediate IOFB removal.^{6,29–32} In this study, IOFB removal was completed in 118 patients (71.08%) at an average of 31.67 days after injury, with only 1 case of likely postoperative endophthalmitis reported. Historically, it has been suggested that the advantages of immediate IOFB removal include decreased risk of endophthalmitis, decreased rate of PVR, and avoiding a second surgery.³³ A review by Colyer et al⁶ showed that there were no cases of endophthalmitis in 79 patients who had early closure and delayed removal of IOFB with topical and oral antibiotics (median removal at 21 days). Delayed removal in combat ocular trauma was often owing to orthopedic and neurosurgical trauma that superseded ocular surgery. Colyer et al⁶ found that IOFB removal can be delayed if there is primary closure within hours of injury and topical/systemic antibiotics are initiated. In that review, 97% of patients received antibiotics; a large majority received both systemic levofloxacin and topical moxifloxacin. Only 3 patients received intravitreal antibiotics. In addition, time to IOFB removal was not found to be a statistically significant factor ($P = 0.489$) for the development of PVR. In our

study, IOFB time to removal was not found to be related to later development of PVR in univariate analysis ($P = 0.11$; Table 5). The advantages^{6,33} of delayed IOFB removal include permitting time for spontaneous posterior vitreous detachment or for resolution of media opacities, including corneal edema and hyphema, which may allow for easier vitrectomy and removal.

The rate of PVR in patients with an IOFB was 26.5% ($n = 44$) in all eyes. In patients who had an IOFB and a retinal detachment ($n = 48$ [28.9%]), the rate of PVR was 47.9% ($n = 23$). The reported range of PVR in patients with IOFB can vary from 6.67% to 46.1%.^{6,34-39} Colyer et al⁶ found that severe injury of >4 structures ($P < 0.001$) and poor presenting vision ($P = 0.025$) were associated with PVR, but not zone of entry ($P = 0.227$), IOFB composition ($P = 0.311$), or time to IOFB removal ($P = 0.489$). In our study (Table 6), univariate analysis of just patients with IOFB showed multiple risk factors for the development of PVR, including subretinal and macular hemorrhage, retinal detachment, and zone of injury. In addition, IOFB depth of penetration was reviewed by final location starting in the anterior chamber, lens, vitreous, retina, subretinal space, choroid, sclera, and perforated sclera. Patients with a deeper penetration of the IOFB were more likely to have a PVR ($P < 0.001$). Regarding IOFB characteristics, only the volume of the largest IOFB ($P = 0.02$) was predictive of the development of PVR, whereas duration of time to removal ($P = 0.11$) and total number of IOFB ($P = 0.97$) were not.

Surgical management for IOFB has been varied; however, a review by Yeh et al³³ gives an effective algorithm for management of IOFB, particularly outlining IOFB removal site, intraocular lens placement, and type of tamponade to use. In the past few years, new studies outlining the use of 23-gauge^{40,41} and 25-gauge^{42,43} PPV for IOFB removal have been written. In our study, pars plana vitrectomy was the most common surgery and was performed in 124 eyes (74.70%) with 20-gauge instrumentation. IOFB removal was completed in 118 eyes (71.08%). IOFB removal was not accomplished at WRAMC owing to logistical reasons or patient preference. Some patients were only at WRAMC for a short period and their long-term follow-up was completed at a different military medical center where the IOFB removal may have been completed. Pars plana lensectomy in 78 (46.99%) and cataract extraction with posterior chamber intraocular lens placement in 43 (25.90%) were completed commonly. As discussed in Yeh et al,³³ the decision to place an intraocular lens should be determined based on whether there is an adequate capsule.

There were multiple limitations to this study. Primarily, there was relatively poor longitudinal patient data tracking from the point of injury to WRAMC. Analysis of the data was complicated by incomplete records, difficulty in long-term tracking of soldiers once they left WRAMC, and impediments documenting initial VA, making OTS and initial VA outcomes troublesome to assess.

In conclusion, this study demonstrated that there is a high frequency of IOFB in war-time trauma (18.65%) and approximately 41.57% remained legally blind

(VA $< 20/200$) after treatment. Critically, however, IOFB itself is not a risk factor for a final VA of $<20/200$ ($P = 0.10$) beyond associated injuries that are known risk factors for blindness such as retinal detachment, phthisis, globe rupture or perforation, and optic nerve injury (all $P < 0.001$). Although more patients with IOFBs had an OTS grade of 3 to 5, compared with patients without an IOFB, IOFB was positively associated with OTS grade 1 to 2 (0–65) injuries (OR, 1.58; 95% CI, 1.07–2.38; $P = 0.01$). IOFB was negatively associated with TBI (OR, 0.51; 95% CI, 0.34–0.75; $P < 0.001$) and no significant association was found with optic nerve injuries (OR, 0.36; 95% CI, 0.32–1.37; $P = 0.36$). This finding was likely owing to the further proximity from IED blasts with less severe injuries and demonstrates that, if eye protection use could be increased, the rate of IOFB and associated injuries may decrease. Finally, there is a critical need for further prospective, randomized research into the timing of IOFB removal, the use of intravitreal antibiotics, and the mechanism of PVR in patients with an IOFB.

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Abbreviations and Acronyms:

CI = confidence interval; **IED** = improvised explosive device; **IOFB** = intraocular foreign bodies; **OIF/OEF** = Operation Iraqi Freedom/Operation Enduring Freedom; **OR** = odds ratio; **OTS** = Ocular Trauma Score; **PPV** = pars plana vitrectomy; **PVR** = proliferative vitreoretinopathy; **TBI** = traumatic brain injury; **VA** = visual acuity; **WRAMC** = Walter Reed Army Medical Center; **WROTD** = Walter Reed Ocular Trauma Database.

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Hyphema in Open-Globe Versus Closed-Globe Injuries in Operation Iraqi Freedom and Enduring Freedom: 2001–2011

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ABSTRACT Introduction: The goal of this study is to update the incidence of hyphema in Operation Iraqi (OIF) and Enduring Freedom (OEF). We wanted to assess associated ocular injuries and final visual acuity (VA) in open-globe versus closed-globe injuries with a hyphema. Materials and Methods: We performed a retrospective review of the Walter Reed Ocular Trauma Database (WROTD) to identify U.S. Service members and DoD civilians with hyphema who were evacuated to Walter Reed Army Medical Center between 2001 and 2011. Primary outcome measures were the final VA and differences in concomitant ocular injuries in open-globe hyphema and closed-globe hyphema. Results: 168 of 890 eyes (18.9%) in the WROTD had a hyphema. Closed-globe injuries were noted in 64 (38.1%) eyes and open-globe injuries in 104 (61.9%) eyes. A final VA of less than 20/200 was noted in 88 eyes (51.8%). Eyes with hyphema were more likely to have traumatic cataract formation (odds ratio (OR) 6.2, 95% confidence interval (CI) 4.2–9.2, $P < 0.001$), retinal detachment (OR 4.2, CI 2.8–6.4, $P < 0.001$), angle recession (OR 8.1, CI 2.9–24.3, $P < 0.001$), and final VA of less than 20/200 (OR 3.7, CI 2.6–5.4, $P < 0.001$). Traumatic cataract formation (OR 7.4, CI 2.9–18.7, $P < 0.001$), retinal detachment (OR 6.1, CI 2.1–17.5, $P < 0.001$), and a final VA less than 20/200 (OR 6.1, CI 2.4–15.4, $P < 0.001$) were statistically more likely to occur with an open-globe hyphema than with a closed-globe hyphema. Conclusions: Close follow-up in patients with hyphema is important due to the associated development of traumatic cataract and retinal detachment and poor final visual outcome.

INTRODUCTION

Combat ocular injuries have increased steadily in wars involving U.S. Service members from 0.5% in the American Civil War¹ to 2.0% in World War I and II^{2,3}, and now 13% in Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF)⁴. From 2003 to 2006 in OIF and OEF, hyphema was a notable presentation among U.S. Service members occurring in 18.2% of ocular injuries⁴. This study examined the inci-

dence of hyphema in open-globe versus closed-globe injuries in U.S. Service members and Department of Defense civilians in OIF and OEF from 2001 to 2011. In addition, we analyzed final visual acuity (VA), ocular trauma scores (OTS), surgical interventions, and the incidence of additional ocular injuries in both open-globe and closed-globe hyphemas, including glaucoma, traumatic cataract formation, angle recession, and retinal detachment.

MATERIALS AND METHODS

This study is a retrospective analysis of data contained within the Walter Reed Ocular Trauma Database (WROTD), a record of ocular injuries from OIF (Iraq) and OEF (Afghanistan) from 2001 to 2011 collected as part of an ongoing approved institutional review board protocol at Walter Reed National Military Medical Center. The patients in the WROTD were treated at combat support hospitals (CSH) before evacuation, in most cases, to Landstuhl Regional Medical Center (LRMC) and subsequently to the former Walter Reed Army Medical Center (WRAMC). The WROTD was populated by data from inpatient and outpatient records, transfer summaries, and operative reports. The database contains data from most U.S. Service members and DoD civilians with ocular injuries sustained during this OIF and OEF with the exception of patients with severe burns who were evacuated to San Antonio Military Medical Center and select Navy and Marine patients who were evacuated to Balboa Naval Medical Center in San Diego, CA. Previous studies^{5,6} further describe the data collection methodology in the WROTD.

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Inclusion criteria for this study were any U.S. Service member or Department of Defense (DoD) civilian injured in OIF/OEF with a hyphema. Study population final VA and differences in incidence of additional ocular injuries in open-globe hyphema and closed-globe hyphema were the primary outcome measures; surgical procedures performed, mechanism of injury, and ocular trauma score (OTS) were the secondary outcome measures.

Because of the extensive and life-threatening nature of battle-injuries, the need for resuscitation and stabilization, and the depressed levels of consciousness, patients frequently could not have their VA tested until after initial ocular and/or non-ocular resuscitative surgery and often not until they had arrived at WRAMC. The study protocol included the collection of the post-injury VA at the earliest possible opportunity, 30 days after first recorded visual acuity, 6 months after first recorded visual acuity, and the last documented visual acuity date. In many cases, only initial VA and final VA were recorded into the database. Initial and final VA was converted from Snellen acuity to vision grades for statistical analysis: grade 1 = 20/40 or better, grade 2 = 20/50–20/200, grade 3 = 19/200–1/200, grade 4 = hand motion or light perception, and grade 5 = no light perception.^{5–6} Ocular trauma data was collected from each subject until entry into the veterans affairs medical system, return to unit, or permanent change of duty station. The ocular injuries were classified as different types of open-globe and closed-globe injuries according to the Birmingham Eye Trauma Terminology (BETT).^{7–9} In addition, the OTS for each subject was calculated as described by Kuhn et al.¹⁰ and then converted to grades based upon the score for statistical analysis: grade 1 = 0–44, grade 2 = 45–65, grade 3 = 66–80, grade 4 = 81–90, grade 5 = 91–100 with grade 1 having the worst prognosis, and grade 5 having the best prognosis.

Univariate analysis was completed using Fisher's exact test. Odds ratios (OR) and 95% confidence intervals (CIs) given for categorical variables were also computed via Fisher's exact test. To separately analyze the impact of injury type (open-globe vs. closed-globe) and hyphema (yes vs. no) on the likelihood of having an additional ocular injury, a series of binomial models was constructed. For proportions and incidence rates, the Agresti and Coull method¹¹ was used to calculate confidence intervals (CI). Univariate and multivariate analyses discarded cases with missing information and analyzed records in which none of the variables tested in that analysis had missing values. Proportions and incidence rates counted the total number of positive incidences over the total number of eyes. Alpha was set at 0.05 for all analyses.

RESULTS

Demographics

One hundred and sixty-eight out of 890 eyes (18.9%) from the WROTD were found to have had a hyphema. The average

age of the injured U.S. Service members and DoD civilians was 27.5 years (standard deviation 8.04, range 18–52). 97.0% of eye injuries occurred in male patients. Of the 168 eyes with hyphema, 134 (79.8%) occurred in OIF and 34 (20.2%) in OEF. The mechanism of injury varied, but in 118 eyes (70.2%) was due to an improvised explosive device (IED; [Supplementary Table 1](#)).

Zones of injury for open-globe and closed-globe injuries as defined by the BETT were recorded. Closed-globe zone 2 and 3 injuries occurred in 14/168 (8.33%) and 50/168 (29.76%) eyes, respectively. Open-globe zone 1, 2, and 3 injuries happened in 22/168 (13.10%), 19/168 (11.31%), and 63/168 (37.50%) eyes, respectively. Sixty-three (37.5%) eyes suffered a bilateral globe injury and 6 (3.6%) suffered a globe-adnexal injury.

Associated Injuries and Surgeries

Associated ocular and head and neck injuries in patients with hyphema are listed in [Table I](#). Patients also underwent a variety of ophthalmic surgical procedures for various hyphema-related closed-globe and open-globe injuries. These were performed at the CSH, LRMC, and WRAMC and are listed in [Supplementary Table 2](#).

Visual Acuity and OTS

Initial and final VA grades and OTS are presented in [Table II](#). Regarding the change in VA from initial VA to final recorded VA for patients with a hyphema, 7 (4.2%) were unknown, 6 (3.6%) were initially intubated, 55 (32.7%) had no change, 87 (51.8%) demonstrated improvement, and 13 (7.7%) decreased.

Statistical Analysis

The odds ratio (OR) of having a hyphema and a concomitant ocular injury is presented in [Table III](#). Ocular injuries with a hyphema were found to have a significant association with traumatic cataract, retinal detachment, or angle recession (all, $P < 0.001$). Additionally, the odds of having an OTS grade of 1 or 2 and worse than 20/200 final VA are significantly higher in eyes with hyphema than eyes without a hyphema in the WROTD ($P < 0.001$). There was no significant difference in the development of glaucoma in patients with and without a hyphema in the WROTD ($P = 0.5$). In addition, a comparison of open-globe versus closed-globe hyphemas was completed ([Table IV](#)). In eyes with open-globe hyphema, the odds were significantly higher for developing a traumatic cataract and retinal detachment and were associated with a worse OTS and final VA ($P < 0.001$). There was no significant difference between open-globe and closed-globe hyphemas in the development of angle recession or glaucoma ($P = 0.1$ and 0.96, respectively).

TABLE I. Associated Ocular and Head and Neck Injuries

Neuro-Ophthalmic Injuries	
Direct optic nerve injury	21 (12.5%)
Optic nerve avulsion	4 (2.4%)
Anterior segment injuries	
Conjunctival chemosis	14 (8.3%)
Corneal abrasion	8 (4.8%)
Corneal laceration	43 (25.6%)
Corneal foreign body	22 (13.1%)
Corneal scar	30 (17.9%)
Corneoscleral laceration	40 (23.8%)
Scleral lacerations	51 (30.4%)
Iritis	10 (6.0%)
Iris injury	74 (44.0%)
Sphincter tear	15 (8.9%)
Iridodialysis	41 (24.4%)
Angle injury	28 (16.7%)
Angle recession	13 (7.7%)
Glaucoma	4 (2.4%)
Zonular dehiscence	15 (8.9%)
Cataract	90 (53.6%)
Aphakic	7 (4.2%)
Dislocated lens	8 (4.8%)
Subluxed vitreous	2 (1.2%)
Posterior segment injuries	
Vitreous hemorrhage	136 (81.0%)
Intraocular foreign body	14 (8.3%)
Rupture	15 (9.0%)
Posterior rupture	12 (7.1%)
Comotio	64 (38.1%)
Chorioretinal rupture	23 (13.7%)
Chorioretinal rupture involving the macula	17 (10.1%)
Retinal hemorrhage	112 (66.6%)
Macular hemorrhage	44 (26.2%)
Retinal tears	64 (38.1%)
Retinal detachment	61 (36.3%)
Macular holes	6 (3.6%)
Choroidal hemorrhage	56 (33.3%)
Choroidal hemorrhage involving the macula	41 (24.4%)
Choroidal rupture	14 (8.3%)
Choroidal rupture involving the macula	12 (7.1%)
Vascular injuries	8 (4.8%)
Phthisis	20 (11.9%)
Orbital/adnexal injuries	
Retrobulbar hemorrhage	15 (8.9%)
Lid injury	81 (48.2%)
Orbital fractures	54 (32.1%)
Orbital foreign bodies	30 (17.9%)
Head and neck injuries	
Cranial nerve injuries	9 (5.4%)
Facial injury	85 (54.8%)
Neck injury	7 (4.5%)
Skull fracture	13 (8.4%)
Traumatic brain injury	53 (34.2%)

DISCUSSION

This study and an earlier study⁴ from OIF and OEF show rates of hyphema of 18.9% and 18.2%, respectively, in patients with ocular trauma. In this study, IED blasts were the most common mechanism for traumatic hyphema, leading to predominantly open-globe hyphema (61.9%). In civilian trauma data, the

mean annual incidence of hyphema ranges between 0.0002 and 0.017%.^{12,13} Closed-globe injury secondary to playing a sport¹⁴ is the most common cause of traumatic hyphema in civilian data. Additionally, in several urban civilian hospitals, blunt ocular trauma accounts for two-thirds of traumatic hyphemas.^{14,15}

TABLE II. Ocular Trauma Score and Visual Acuities

Ocular Trauma Score	#	%	Initial Visual Acuity Grade	#	%	Final Visual Acuity Grade	#	%
0–44	35	20.8%	Grade 1	16	9.5%	Grade 1	64	38.1%
45–65	50	29.8%	Grade 2	14	8.3%	Grade 2	12	7.1%
66–80	45	26.8%	Grade 3	19	11.3%	Grade 3	14	8.3%
81–90	14	8.3%	Grade 4	74	44.1%	Grade 4	29	17.3%
91–100	15	8.9%	Grade 5	36	21.4%	Grade 5	44	26.2%
Unknown	9	5.4%	Unknown	9	5.4%	Unknown	5	3.0%

Grade 1 = 20/40 or better, grade 2 = 20/50–20/200, grade 3 = 19/200–1/200, grade 4 = hand motion or light perception, grade 5 = no light perception.

TABLE III. Risk of Associated Injuries and of Poor Final Visual Acuity in Patients with Hyphema Compared to Those Without Hyphema in the WROTD

Variable	Hyphema: No Hyphema Odds Ratio (OR)	Hyphema: No Hyphema 95% Confidence Interval (CI)	P-Value
Cataracts	6.2	4.2–9.2	<0.001
Retinal detachment	4.2	2.8–6.4	<0.001
Angle recession	8.1	2.9–24.3	<0.001
OTS grade 1 or 2 (0–65)	3.3	2.2–4.8	<0.001
Final VA < 20/200	3.7	2.6–5.4	<0.001
Glaucoma	1.5	0.3–5.1	0.51

TABLE IV. Risk of Associated Injuries and of Poor Final Visual Acuity in Patients with Open-Globe Versus Closed-Globe Hyphema

Variable	Open-Globe: Closed-Globe Hyphema OR	Open-Globe: Closed-Globe Hyphema CI	P-Value
Cataracts	7.4	2.9–18.7	<0.001
Retinal detachment	6.1	2.1–17.5	<0.001
Angle recession	0.3	0.1–1.2	0.11
OTS grade 1 or 2 (0–65)	6.8	2.6–17.7	<0.001
Final VA < 20/200	6.1	2.4–15.4	<0.001
Glaucoma	0.6	0.1–8.2	0.96

Studies have demonstrated poor visual quality of life after combat ocular injuries, causing a significant health care and social burden when these patients must reintegrate into life upon returning home.^{5,16} Many of the eyes in this study suffered severe injuries with an ocular trauma score (OTS) of 1 or 2 (85/168, 50.6%), with lower scores representing a poorer final visual prognosis. In addition, 88/168 eyes (51.8%) had a final visual acuity of less than 20/200. Our study found that there were significantly higher odds of a lower OTS and poorer final VA in eyes with hyphema compared to those without a hyphema and in eyes with an hyphema and open-globe injury compared to those with a hyphema and closed-globe injury.

As demonstrated in Table I, patients with hyphema often had multiple concurrent ocular injuries affecting different components of the eye and adnexa. The high incidence of additional ocular injuries associated with traumatic

hyphema underscores the importance of following patients for these additional injuries, especially for traumatic cataract formation, glaucoma, angle recession, and rebleeding. These injuries require long-term close observation and treatment to prevent vision loss. Traumatic cataract formation complicated 53.6% of hyphemas in this study. This is higher than a previously reported civilian rate of 20.6%.¹⁷ Glaucoma occurred in only 2.4% of hyphemas in the WROTD, while in contrast the incidence in civilian trauma data has been reported between 0 and 33%.^{15,17} Glaucoma has been documented as a complication of hyphema since the 1970s–1980s in the context of sickle cell disease and trait^{18–20} and intraocular lens (IOL) implant-related uveitis-glaucoma-hyphema syndrome (UGH).²¹ Civilian data found that hyphema is an independent risk factor for glaucoma surgery²². This study's rate of glaucoma in hyphema falls in the range of civilian rates; however, it is likely that this study underestimates glaucoma

incidence, as the WROTD only tracked patient complications for a limited and variable period.

Angle recession in patients with hyphema occurred less frequently in this study than in the literature. In one study, 60% of traumatic hyphemas were complicated by anterior chamber angle recession, as compared to our rate of 7.7%.²³ Angle recession can occur from several theoretical mechanisms in blast injuries, including primary (shock wave), secondary (foreign bodies), and tertiary blast injury effects (soldier as a projectile hitting a stationary object). The low rate of angle recession complicating hyphemas in this study is likely due to several factors including the limited numbers of closed-globe hyphemas in comparison to open-globe hyphemas, limited and variable periods of follow-up, and inability to perform gonioscopy on many of the patients prior to transfer or discharge.

Rebleeding is another important complication of traumatic hyphema. The reported risk of rebleeding in the literature is as high as 18%.²⁴ Rebleeding has been associated with visual acuity of less than or equal to 6/60 (20/200) at discharge (OR = 10.5, 95% CI = 3.7–29.2).¹⁹ The rate of rebleeding was not measured in the WROTD due to the frequent provider changes intrinsic to a medical evacuation system beginning in combat at the point of injury and ending at WRAMC. By the time of arrival to WRAMC, most patients were outside of the usual window of rebleed of 2–7 days.

Almost 10% of patients with hyphema in this study had an intraocular foreign body (IOFB; Table I). IOFBs occur with a high frequency in combat injuries.²⁵ In data from the WROTD, IOFBs occurred in 18.6% of eyes, and of these, hyphema was noted in 36.14% of patients. Patients with an IOFB had an OR of 3.3 (2.2–4.9, $P < 0.001$) of having a hyphema. In addition, as domestic terrorists begin to use similar bomb building techniques as those used to make IEDs in OIF and OEF, such as at the Boston Marathon²⁶, IOFB injuries from explosions could become more commonplace. If a patient presents with a trauma-related hyphema, it is critical to presume an IOFB until ophthalmic evaluation rules one out.

There were multiple limitations to this study. First, the data analyzed in this study was retrospectively aggregated from soldier and physician documentation. Each subject was followed for a limited and variable period. As such, some of the data points were incomplete. In addition, while rebleed and sickle cell disease incidence have often been reported in studies on hyphema, this data was not available for the analysis in the WROTD.

In conclusion, 18.9% of eyes with ocular injuries in OIF and OEF had a traumatic hyphema. Of these combat-related traumatic hyphemas, the majority were open-globe injuries (61.9%) secondary to IED blasts. In addition, these patients presented with a wide diversity of concurrent ocular injuries affecting both the eye and adnexa. Open-globe hyphema, when compared to closed-globe hyphema, was more likely to be associated with traumatic cataract formation, retinal detachment, OTS grade 1 or 2, and final visual acuity less

than 20/200 (all $P < 0.001$). These observations underscore the importance of close lifetime follow-up of all patients with both closed- and open-globe trauma hyphema to prevent loss of visual function.

SUPPLEMENTARY DATA

Supplementary data are available at *MILMED* online.

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CONFLICT OF INTEREST

No conflicting relationship exists for any author.

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Posterior Segment Injuries in Operation Iraqi Freedom and Operation Enduring Freedom: 2001-2011

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Army Office of the Surgeon General, the Department of the Air Force, the Department of the Army, Department of Defense, the Uniformed Services University of the Health Sciences or any other agency of the U.S. Government.

Brief Summary Statement

Posterior segment injuries occur in about 50% of eyes with wartime injuries and of those approximately 50% have a final visual acuity less than 20/200. Open globe, and Zone II and III injuries more commonly result in a poor final visual outcome.

Abstract:

Objective: To characterize the nature of posterior segment ocular injuries in combat trauma.

Methods: Eyes in the Walter Reed Ocular Trauma Database were evaluated for the presence of posterior segment injury. Final visual outcomes in open- versus closed-globe injuries and by zone of injury, and the types of posterior segment injuries in open- versus closed-globe injuries were assessed.

Results: 452 of 890 eyes (50.8%) had at least one posterior segment injury. The mechanism of injury was most commonly an improvised explosive device in 280 (62.0%) eyes. 61 (13.5%) patients had a Zone I injury, 50 (11.1%) a Zone II injury and 341 (75.4%) a Zone III injury. Patients with Zone I injuries were more likely to have a final VA of 20/200 or better compared to

patients with either a Zone II ($p < 0.001$) or Zone III injury ($p = 0.007$). Eyes with a closed-globe injury were more likely to have a final VA of 20/200 or better compared to those with an open-globe injury ($p < 0.001$). Further, closed-globe compared to open-globe injury had a lower risk of vitreous hemorrhage (OR 0.32, $p < 0.001$), proliferative vitreoretinopathy (OR 0.14, $p < 0.001$), and retinal detachment (OR 0.18, $p < 0.001$), but higher risk of chorio-retinal rupture (OR 2.82, $p < 0.001$), and macular hole (OR 3.46, $p = 0.004$).

Conclusions: Patients with combat ophthalmic trauma had similar posterior segment injury patterns to civilian trauma in open- versus closed-globe injuries. Zone II and III injuries were associated with a worse visual prognosis.

Keywords

Combat injuries, Open Globe Injuries, Closed Globe Injuries, Zone of Injury, Improvised Explosive Device

Introduction:

Ocular trauma is associated with devastating outcomes for visual acuity (VA) and quality of life. Developing an understanding of ocular trauma is an important yet complex challenge given the variety of mechanisms of injury and variation in impact on ocular anatomy. During wartime conflict, the mechanisms of injury depend on the type of conflict and the specific weapons employed with subsequent variation in frequency and type of ocular injury depending

on the combat setting ranging from WWI through Desert Storm.¹ Furthermore, there seems to be a notable increase in the frequency of combat ocular trauma (COT) throughout the past century.^{1,2} In modern conflicts, COT predominantly occurs secondary to blast injuries of varying types. The posterior segment can be damaged in these injuries and is associated with a worse visual prognosis.^{3,4} Pieramici et. al. characterized traumatic ocular injury into three anatomic regions or zones by open- versus closed-globe injuries.⁵ Previous studies have found that open-globe trauma with injuries in Zone II and III is associated with higher rates of retinal detachment (RD) and other posterior segment injuries, leading to worsened visual outcomes and a higher risk of blindness.^{4,6}

The purpose of this study is to further characterize the nature of posterior segment ocular injuries in U.S. Service members during Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF) from 2001-2011. The primary endpoints of this study included final VA and different posterior segment injury types in open-globe versus closed-globe injuries, as well as the final visual outcomes by zone of injury.

Materials and Methods:

The data source for this retrospective study comes from the Walter Reed Ocular Trauma Database (WROTD). This large repository contains information for US service members who suffered ocular trauma during OIF and OEF and who were subsequently treated at the former Walter Reed Army Medical Center (WRAMC). Injuries in theater were managed by deployed ophthalmologists at a Combat Support Hospital (CSH) near the location of conflict. Following

initial treatment, patients were either evacuated to WRAMC directly, or treated at Landstuhl Regional Army Medical Center (LRAMC) in Germany prior to being transferred to WRAMC. These patients were tracked until one of three things happened: (1) they were accepted into the US Veteran's Affairs medical system for treatment, (2) they underwent a permanent change of duty station, or (3) they returned to their source unit. Data was documented within Microsoft's Excel spreadsheet software (Microsoft Corporation, Redmond, WA). More detailed information on the collection of data for the WROTD has been described in previous publications and a detailed summary is deferred in the current study.^{6,7}

Inclusion criteria included any US service member or Department of Defense (DoD) civilian injured in OIF/OEF with a posterior segment injury including vitreous hemorrhage (VH), vitreous base avulsion, commotio retina, macular commotio, chorioretinal rupture, subretinal hemorrhage, intraretinal hemorrhage, macular hemorrhage, retinal tear (RT), macular hole, RD, choroidal hemorrhage (CH), choroidal rupture, and/or those patients that underwent a pars plana vitrectomy (PPV). Exclusion criteria included patients without one of the injuries listed above and/or isolated ophthalmic non-posterior segment injury. The primary outcome measure was final visual outcomes in open- versus closed-globe injuries, and by zone of injury. In addition, the rates of different posterior segment injuries in open versus closed-globe injuries were assessed.

Ocular injuries were organized based on the Birmingham Eye Trauma Terminology (BETT) put forth by Kuhn et. al.^{5,8} Using Snellen acuities, vision was graded on a scale from 1 to 5 to allow for statistical analysis.^{3,6} These VA groups were chosen over traditional LogMAR analysis given the large number of poor seeing eyes in our database – a reflection of the severity of ocular trauma in combat. VA of 20/40 or better was classified as Grade 1, 20/50 to 20/200 was

Grade 2, 19/200 to 1/200 was Grade 3, hand motion or light perception was Grade 4, and no light perception was classified as Grade 5. The complexities of COT resulted in a variation in how initial VAs were obtained. When possible, all VAs were recorded when the patient was first awake following trauma. As such, the timing varied based on the severity of triaged ocular injury and concomitant injuries such as traumatic brain injury (TBI). Eye surgery for the ocular damage was frequently performed prior to being able to obtain initial VA for this reason. Per a defined protocol, the last documented visual acuity data was recorded, and if the patient was still at WRAMC, the post-injury visual acuity was tested at 20 to 50 days following injury and 150 to 200 days post-injury. However, due in part to a lack of access to paper records and/or inpatient electronic records, only initial and final VA were recorded into the database. Some patients did not have an initial VA assessed until they arrived for treatment at WRAMC following evacuation from theater. In the subset of patients with posterior segment injuries, 50 eyes were missing initial or final VA and these patients were excluded from the VA analysis.

Statistical analysis was performed using the STATA 14.0 (Microsoft) software as well as SPSS Version 22 (IBM) as previously described. Percentages along with Chi-Squared tests were performed for categorical data. Means and standard deviations were performed for continuous variables. Logistic regression analysis was performed to determine odds ratios along with the corresponding 95% confidence interval. The Type-1 error rate was pre-defined at 0.05.

Results:

Demographics

Of 890 eyes, a total of 452 eyes suffered posterior segment injury (50.8%). The types and frequency of posterior segment injuries are described in Table 1 and surgeries are listed in Supplemental Table 1, <http://links.lww.com/IAE/B485>. Associated anterior segment, neuro-

ophthalmic, oculoplastic, and systemic injuries are included in Supplemental Table 2, <http://links.lww.com/IAE/B486>.

236 (52.2%) injuries were unilateral. Basic demographics as well as mechanisms of injury and data regarding eye protection are highlighted in Table 2. Of the 452 eyes with posterior segment trauma, there were a total of 61 (13.5%) patients with Zone I injuries, 50 (11.1%) with Zone II injuries and 341 (75.4%) with Zone III injuries. One-hundred ninety-two (42.4%) had a closed Zone III injury and 149 (33.0%) had an open Zone III injury. Thirty-eight (8.4%) of patients eventually developed phthisis.

Visual Acuity

For the VA analysis, 50 (11.1%) eyes were missing initial VA (31 eyes; 6.9%) or final VA (19 eyes; 4.2%). These eyes were excluded from the visual acuity analysis. For the 402 eyes of patients who were not intubated and who had an initial and final visual acuity recorded, 222 showed improvement in their visual acuity, 30 demonstrated a decrease in visual acuity and 150 showed no change. There were 395 eyes for which date of injury and date of final visual acuity were available. Follow-up duration was 351.22 days (std. 368.81, range 0-2421 days). One eye included in the analysis had a final visual acuity on the same day of injury (follow-up duration of 0) and the final visual acuity was light perception.

For all eyes who suffered either an open or closed-globe injury (Table 3), those with Zone I injuries were more likely to have a final VA 20/200 or better compared to eyes with either a Zone II ($p < 0.007$) or Zone III injury ($p < 0.001$) injury. There was no significant difference in final VA between eyes that suffered Zone II injuries compared with eyes with injuries in Zone III ($p = 0.15$). When comparing VA by injury type, 102 (25.4%) eyes with open-globe injury had a

visual acuity of 20/200 or better compared to 121 (30.1%) of eyes with a closed-globe injury.

Eyes with a closed-globe injury were more likely to have a final VA of better than 20/200 than those with open-globe injury ($p < 0.001$).

Posterior Segment Injuries in Open vs. Closed-Globe Injury

For all 452 eyes with posterior segment trauma, the risk of vitreous hemorrhage (OR 0.32, $p < 0.001$), choroidal hemorrhage (OR 0.12, $p < 0.001$), proliferative vitreoretinopathy (OR 0.14, $p < 0.001$), retinal tear (OR 0.27, $p < 0.001$), and retinal detachment (OR 0.18, $p < 0.001$) was found to be lower in closed-globe injuries compared to open-globe injuries. However, the risk of commotio retinae (OR 4.69, $p < 0.001$), chorio-retinal rupture (OR 2.82, $p < 0.001$), and macular hole (OR 3.46, $p = 0.004$) was statistically more common in closed-globe injuries compared with open globe trauma (Table 4).

Discussion:

Ocular trauma comprises a significant portion of wartime injuries. In modern conflicts, 13% of all injuries involve the eye making ocular trauma one of the top five most common injuries on the battlefield – an interesting phenomenon given that the eye composes just under 0.3% of the anterior body surface area.⁹ The most prevalent mechanism of injury in modern

combat is high energy explosions with resulting fragmentation either from the munition itself or from debris that are kicked up and propelled secondarily from the blast wave.² In Desert Storm and Desert Shield, the mechanism of injury was explosive fragmentation in 78% of ocular injuries.¹⁰ During the conflicts in Iraq and Afghanistan, studies of U.S. and British service members have reported the etiology of ocular injury to be due to fragmentary explosion in 73%-86% of cases. Subsequently, the leading cause of blindness is open-globe injuries predominantly due to improvised explosive devices (IEDs) (64.2% of cases) with 79% of perforating orbital trauma caused by explosive fragmentation.^{6,11-13} Additionally, data from the WROTD, showed nearly 70% of severe eye injuries resulting in enucleation or evisceration in OIF and OEF were caused by an IED.¹⁴ In this study, IEDs were the cause of injury in 62.0% and rocket propelled grenades (RPGs) were the next most prevalent at 12.8%. Together with mines, mortars and grenades, damage secondary to explosions produced nearly 87% of all injuries.

Posterior segment injuries are common with the type of ocular trauma endured during modern conflict secondary to IEDs. In their analysis of ocular injuries during the Second Lebanese War, Barak et. al. reported 42% of wartime ocular trauma involved the posterior segment.¹⁵ Lashkari et. al. reported 59% of all major wartime ocular traumas during the Iran-Iraq War were associated with posterior segment damage.¹⁶ Similar to these prior reports of combat trauma, of the 890 eyes initially evaluated in this study, a total of 452 (50.8%) suffered posterior segment injury.

As previously mentioned, eye trauma is standardized into open and closed-globe injury according to the Birmingham Eye Trauma Terminology system (BETT).⁸ The incidence of open vs. closed injuries in modern combat varies. Blanch et. al. reported on 58 eye injuries sustained by British military forces in Iraq and Afghanistan, of these 37 (64.3%) were closed-globe injuries

and 21 (36.2%) were open-globe injuries.¹² Looking specifically at the incidence of blindness (final BCVA 20/200 or worse) from trauma in the WROTD, Vlasov et. al. demonstrated a high rate in open-globe injuries (78.6%) compared with closed-globes (21.4%) consistent with an increased severity of this injury type.⁶ In our series of COT with posterior segment injury we also found a higher rate in open-globe injuries with 260 (57.5%) open-globes and 192 (42.5%) closed-globes.

Our results showed a significant difference between several posterior segment injuries in closed versus open-globe injuries. Chorioretinal rupture was higher in closed injuries compared to open ($p < 0.001$). The higher prevalence of traumatic chorioretinal rupture (TCR, also known as sclopeteria or chorioretinitis sclopeteria) in closed-globe trauma is consistent with the classic presentation of TCR from non-penetrating trauma due to a high velocity projectile – classically, a bullet.¹⁷ TCR in COT is often from blasts with high projectile shrapnel. The shrapnel passing near the globe may result in TCR, while separate shrapnel penetrates the globe. This could lead to a higher rate of open globe injuries than would be expected with traditional TCR from bullet injuries. There were 27 (6.0%) macular holes identified in our series with a significantly higher proportion occurring in closed injuries ($p=0.004$). Although they were initially described as a sequela of trauma, macular holes secondary to trauma are less common than previously believed with Ho et. al. reporting a rate of 9-15%.¹⁸ Traumatic macular holes typically occur secondary to contusive trauma, which is commonly seen in closed-globe injury.¹⁹ Civilian trauma-related macular holes are often the result of contusive injury from sports-related ball impact.^{20,21} Earlier in OIF and OEF, Weichel et. al. reported 17 (3.9%) traumatic macular holes out of 435 eye suffering COT.²² Finally, commotio retinae, or “Berlin’s edema”, is a common posterior segment

complication of ocular trauma and in our series was significantly higher in closed injuries ($p < 0.001$).^{23,24}

The anatomic location of ocular trauma has important prognostic implications for visual acuity. Intuitively, posterior segment trauma is associated with a worse visual prognosis than anterior segment trauma.¹⁶ In eyes with penetrating ocular trauma, injuries involving the posterior segment demonstrated a poorer visual prognosis than did eyes with isolated anterior segment injury.²⁵ Zone II and III open-globe injuries are associated with higher rates of RD and posterior segment injuries resulting in a higher risk of blindness.^{4,6,26,27} RD itself has been shown to be strongly associated with poor visual prognosis in open-globe injuries.^{5,27,28} Mudhusudhan et. al. reported open-globe lacerations extending posterior to the equator are associated with a 20-fold increased risk of VA acuity worse than 3/60 compared to lacerations anterior to the insertion of the recti muscles.²⁹ This is similar to the findings of de Juan et. al. who found that wounds in penetrating eye injury that involved the sclera or extended posterior to the rectus muscle insertions were all associated with poor visual outcome (final VA less than 5/200), whereas wounds involving only the cornea have a more favorable visual prognosis.³⁰ In our series of COT with posterior segment injury, eyes with Zone II or Zone III injuries were more likely to have a worse final visual acuity than Zone I injuries ($p < 0.05$).

This study is retrospective and as such is limited by the availability of presenting and follow-up data. This is seen by the wide range of follow-up duration reported. Additionally, our study is unique in that all eye injuries occurred in a combat setting. Recognizing and managing these injury types is drastically different than in the civilian sector which follows the typical pathway of EMS to emergency department (ED) to ophthalmologist. Eye trauma and other injuries in combat requires a complex extraction and evacuation system that ultimately brings the

servicemembers from combat support hospital in theater to a U.S. domestic military hospital, but often requiring a stop in Germany. The nature of the patient's other concomitant injuries may be so severe that their ocular insult is overlooked during stabilization and deployment of life-saving interventions. Thus, in a select number of patients the initial visual acuity data was missing.

These patients were excluded from the VA analysis which limited the number of participants in that portion of this study. Further, there was significant variability in the follow-up time for these patients depending on when they left care at WRAMC, and some patients were missing a final visual acuity. As mentioned previously, only initial and final VA were recorded into the database for several reasons including an inability to access to paper and/or inpatient electronic records, and variability in patient follow-up. Finally, some patients may have undergone further repair or cataract surgery at another location that may have affected their final visual outcome.

In conclusion, out of 890 eyes with ocular trauma evaluated during these conflicts, 50.8% were associated with posterior segment injury. Overall, 223 (55.5%) of eyes had a final visual acuity of 20/200 or better. Eyes with Zone I trauma demonstrated a better visual prognosis than those with Zone II or Zone III trauma, and those with closed-globe injuries had better visual outcomes than open-globe traumas. Posterior segment trauma in combat demonstrates a similar injury pattern to civilian trauma with commotio, macular holes and chorioretinal rupture occurring more commonly in close-globe trauma and vitreous hemorrhage, retinal detachment, retinal tear and proliferative vitreoretinopathy in open-globe trauma.

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Table Legend:

Table 1: Injury Types

Table 2: Demographics and Mechanisms of Injury

Table 3: Zones of Injury

Table 4: Posterior Segment Complication in Open vs Closed-Globe Injury

Table 1: Injury Types

Injury	Injury Subgroup	Cases (n=452)
Vitreous Hemorrhage	Grade 1	73 (16.2%)
	Grade 2	42 (9.3%)
	Grade 3	16 (3.5%)
	Grade 4	161 (35.6%)
	Unknown	40 (8.9%)
Vitreous Avulsion		6 (1.3%)
Comotio Retinae	(-) Macular Involvement	38 (8.4%)
	(+) Macular Involvement	87 (19.2%)
Chorioretinal Rupture	(-) Macular Involvement	42 (9.3%)
	(+) Macular Involvement	42 (9.3%)
Retinal Hemorrhage	Subretinal	148 (32.7%)
	Intraretinal	135 (29.9%)
	Macular	89 (19.7%)
Retinal Tear	Retinal Tear	178 (39.4%)
	Dialysis	14 (3.1%)
	Macular Hole	27 (6.0%)
Retinal Detachment	After open-globe injury	116 (25.7%)
	After closed-globe injury	24 (5.3%)
	(-) Macular Involvement	32 (7.1%)
	(+) Macular Involvement	91 (20.1%)
	1 Quadrant Detached	20 (4.4%)
	2 Quadrant Detached	9 (2.0%)
	3 Quadrant Detached	1 (0.2%)
	4 Quadrant Detached	86 (19.0%)
	Unknown:	10 (2.2%)
Choroidal Hemorrhage	(-) Macular Involvement	45 (10.0%)
	(+) Macular Involvement	77 (17.0%)
Choroidal Rupture	(-) Macular Involvement	14 (3.1%)
	(+) Macular Involvement	22 (4.9%)
Choroidal or Retinal Vascular Injury		12 (2.7%)
Intraocular Foreign Body		148 (32.7%)
Rupture	Anterior	6 (1.3%)
	Posterior	24 (5.3%)

Table 2: Demographics and Mechanisms of Injury

Age (years)	27 (SD 7.29, range 18-53)
Gender	440 (97.4%) Male, 12 (2.7%) Female
Geographic Location of Injury	369 (81.6%) in Iraq, 83 (18.4%) in Afghanistan
Initial Injury Date Range (Year)	2002-2011
Mechanism of Injury	
Improvised Explosive Device	280/452 (62.0%)
Rocket Propelled Grenade	58/452 (12.8%)
Gun Shot Wound	38/452 (8.4%)
Mortar	20/452 (4.4%)
Grenade	19/452 (4.2%)
Other	17/452 (3.8%)
Mine	16/452 (3.5%)
Motor Vehicle Accident	2/452 (0.4%)
Helicopter Crash	1/452 (0.2%)
Unknown	1/452 (0.2%)
Wearing Eye Protection	
Yes	145/452 (32.1%)
No	128/452 (28.3%)
Unknown	179/452 (39.6%)

Table 3: Zones of Injury

Zone of Injury For Open And Closed Injuries				
	Zone I	Zone II	Zone III	Total
20/200 or better	50	25	148	223
Worse than 20/200	9	16	154	179
Totals:	59	41	302	402
Zone I to Zone III	p < 0.001			
Zone I to Zone II	p = 0.007			
Zone II to Zone III	p = 0.15			
Zone of Injury Open-Globe Injuries only				
	Zone I	Zone II	Zone III	Total
20/200 or better	50	25	27	102
Worse than 20/200	9	16	114	139
Totals	59	41	141	241
Zone I to Zone III	p < 0.001			
Zone I to Zone II	p = 0.007			
Zone II to Zone III	p < 0.001			
VA Outcomes for Open Vs. Closed-Globe Injuries				
	Open-Globe Injury	Closed-Globe Injury	Total	
20/200 or better	102	121	223	
Worse than 20/200	139	40	179	
Totals	241	161	402	
	p < 0.001			

Table 4: Posterior Segment Complications in Open vs. Closed-Globe Injury

Closed vs Open Injury	Odds Ratio	Confidence Interval	P-value
Vitreous Hemorrhage	0.32	0.2-0.49	<0.001
Vitreous base avulsion	1.36	0.27-6.81	0.7
Comotio Retinae	4.69	3.01-7.31	<0.001
Chorioretinal rupture	2.82	1.72-4.6	<0.001
Sub-retinal hemorrhage	0.66	0.44-0.99	0.045
Intraretinal hemorrhage	1.12	0.7-1.68	0.6
Macula hemorrhage	0.89	0.56-1.44	0.72
Macular hole	3.46	1.48-8.08	0.004
Choroidal hemorrhage	0.12	0.07-0.21	<0.001
Choroidal rupture	1.86	0.95-3.67	0.08
Proliferative vitreoretinopathy	0.14	0.09-0.22	<0.001
Retinal tear	0.27	0.18-0.41	<0.001
Retinal detachment	0.18	0.11-0.29	<0.001
Dialysis	1.02	0.35-2.98	0.98

Proliferative Vitreoretinopathy After Combat Ocular Trauma in Operation Iraqi Freedom and Operation Enduring Freedom: 2001-2011

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BACKGROUND AND OBJECTIVE: To determine the risk factors associated with developing proliferative vitreoretinopathy (PVR) from combat ocular injuries in U.S. service members.

PATIENTS AND METHODS: Retrospective review of associated risk factors and outcomes of PVR within the Walter Reed Ocular Trauma Database. Ocular injuries in U.S. service members wounded during Operation Enduring Freedom and Operation Iraqi Freedom from 2001 to 2011 were assessed, and of these all cases of PVR were studied. Principal outcome measures were the risk factors associated with PVR development and rate of final visual acuity (VA) less than 20/200.

RESULTS: Eight hundred ninety eyes of 651 U.S. service members were evaluated. A total of 76 eyes (8.5%) of 66 patients developed PVR. Five patients had bilateral PVR. Nineteen patients had bilateral eye injuries. Sixty-one eyes (80.2%) had a final VA less than 20/200. PVR was found to be a significant risk factor for a poor final VA ($P < .001$). Retinal detachment (RD) was found in 52 eyes (68.4%) of patients. In patients with a RD, intraocular foreign bodies (IOFBs) ($P < .001$), unsuccessful repair ($P = .002$), and macular hemorrhage ($P = .04$) were significant risk factors for the development of PVR. Time to initial retina surgery was not found to be a risk factor for PVR development ($P = .5$). Time to initial retina surgery was available in 41 patients and the time to surgery on average was 22.56 days (range: 3 to 87 days).

CONCLUSIONS: PVR occurs frequently in combat trauma and is a significant cause of poor final VA. In patients with PVR and RD, injuries caused by an IOFB, macular hemorrhage, or unsuccessful repair were significant risk factors for the development of PVR.

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INTRODUCTION

Traumatic ocular injury is the leading cause of vision loss in young adults.¹ In contrast to the civilian population, ocular trauma experienced by U.S. service members is usually of increased severity.² In Operations Iraqi and Enduring Freedom (OIF/OEF, Iraq/Afghanistan), 13% of U.S. service members injured in combat had a traumatic ocular injury requiring evacuation from theater.³ A traumatic ocular injury affecting the posterior segment generally has a poorer prognosis compared to an anterior segment injury.^{3,4}

Proliferative vitreoretinopathy (PVR) is a common cause of decreased vision after retinal detachment (RD) and ocular trauma. Classically, PVR was noted to be secondary to RD and its repair.⁵⁻⁷ However, further research has shown that the etiopathogenesis of PVR is significantly more complicated particularly in patients with trauma.⁸⁻¹⁰ PVR has been reported after laser treatment of retinoblastoma and treatment of syphilitic uveitis.^{11,12} In patients with a primary RD, the rate of PVR is 8% to 10%,

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whereas in those with ocular trauma, it can be as high as between 40% to 60%.¹⁰ This high rate in ocular trauma is likely due to the inflammatory cascade, a breakdown of the blood-retinal barrier, and direct introduction of cells from outside the eye.^{10,13} The development of PVR in association with RD poses a threat to the adequate repair and prognosis of the reattached retina.^{14,15} The importance of elucidating the risk factors associated with developing PVR specifically in injuries sustained from combat trauma and the connection between PVR and RD is of significant clinical importance. As patients who develop PVR after RD repair have a worse prognosis than those without PVR,^{16,17} understanding risk factors for PVR development might lead to better identification of high-risk patients and consideration of different more aggressive therapy such as silicone oil versus gas placement.

The goals of this study were to assess the risk factors associated with the development of PVR in all patients and in those with a RD. An evaluation of the rate of poor final visual acuity (VA) in patients with PVR was completed.

PATIENTS AND METHODS

The Walter Reed Ocular Trauma Database (WROTD) contains data on ocular injuries to U.S. service members evacuated from combat support hospitals (CSHs) in OIF and OEF. Upon evacuation from the CSH, most patients were managed at Landstuhl Regional Medical Center (LRMC) in Landstuhl, Germany, before then being transferred to Walter Reed Army Medical Center (WRAMC) in Bethesda, Maryland, for further treatment. These data were collected over 10 years from 2001 to 2011 and consisted of patient records from initial injury through arrival at WRAMC. Data were collected throughout their stay at WRAMC until they were released back to service or were entered into the Veterans Affairs medical system using Microsoft Excel (Microsoft Corporation, Redmond, WA) and stored on SPSS (IBM, Armonk, NY). Statistical analysis was completed using R statistical software (R Foundation for Statistical Computing, Vienna, Austria).

All cases of ocular trauma from 2001 to 2011 involving U.S. service members or Department of Defense civilians injured in OIF and OEF evacuated to WRAMC were included. All vitreoretinal surgeries occurred at WRAMC, as there was no vitreoretinal surgery capability at a CSH or LRMC. Of these, all cases of documented PVR were studied. Primary outcome measures were the incidence of PVR and risk factors for the development of PVR in all pa-

OTS Grade	No. of Eyes	%
0-44	21	27.6%
45-65	33	43.4%
66-80	12	15.8%
81-90	2	2.6%
91-100	1	1.3%
Unknown	7	9.2%

OTS = ocular trauma score

tients and those with RD. Secondary measures were final visual outcome and associated injuries.

The Birmingham Eye Trauma terminology was used to describe injuries.¹⁸⁻²⁰ As previously described the Snellen VA were converted to vision grades.²¹ Grade 1 was defined as 20/40 or better, Grade 2 was 20/50 to 20/200, Grade 3 was 19/200 to 1/200 (count fingers), Grade 4 was hand motion or light perception, and Grade 5 was no light perception. The ocular trauma scores (OTS) were computed as previously described.²²

Statistical Analysis

For statistical analysis, patients with PVR were separated into two different categories. The first group were any patients who had documented PVR, and the second group were those who had a documented PVR and RD. Ocular trauma has a high rate of development of PVR, likely due to the subsequent inflammatory cascade, breakdown of the blood-retinal barrier, and direct introduction of cells from outside the eye.^{10,13} In Cardillo et al., a study similar to the current study evaluating the rate of PVR in patients with ocular trauma, PVR was noted in 71 injured eyes, but only 54 had a documented retinal detachment.⁹ For this reason, the authors felt that it was appropriate to evaluate risk factors for the development of PVR in two separate analyses, those with PVR, and those with PVR and RD.

Fisher's exact test and Wilcoxon rank-sum test with continuity correction were used for univariate analysis; Fisher's exact test was also used to compute odds ratios and 95% confidence intervals (CIs). Multivariate analysis was completed using binomial logistic regression. Type 3 likelihood ratio test as implemented in the "car" package was used to evaluate significance.²³ Alpha was set at .05 for all analyses.

TABLE 1B
Initial Visual Acuity and Final Visual Acuity Grades

Initial VA Grade	No. of Eyes	%	Final VA Grade	No. of Eyes	%
Grade 1	1	1.3%	Grade 1	5	6.6
Grade 2	3	3.9%	Grade 2	8	10.5
Grade 3	4	5.3%	Grade 3	9	11.8
Grade 4	46	60.5%	Grade 4	29	38.2
Grade 5	15	19.7%	Grade 5	23	30.3
Unknown	7	9.2%	Unknown	2	2.6

Grade 1 was 20/40 or better, Grade 2 was 20/50 to 20/200, Grade 3 was 19/200 to 1/200 (count fingers), Grade 4 was hand motion or light perception, and Grade 5 was no light perception,

VA = visual acuity

TABLE 2
Multivariate Analysis of Risk Factors for Final Visual Acuity Less Than 20/200

Variable	P Value
Proliferative vitreoretinopathy	< .001
Optic nerve injury	< .001
Retinal detachment	< .001
Phthisis	< .001
Penetrating injury	< .001
Globe rupture	< .001

RESULTS

Patient Demographics

Eight hundred ninety eyes of 651 U.S. service members were evaluated from the WROTD. A total of 76 eyes (8.5%) of 66 patients that had developed PVR were analyzed. Nineteen patients had bilateral eye injuries and five patients had bilateral PVR. The average age of the patients was 27.6 years (standard deviation: 7.9; range: 19-50 years). Patients were predominantly male (97.4%). Sixty-six (86.8%) injuries occurred in Iraq, and 10 (13.2%) occurred in Afghanistan.

Zones of Injury

Zones of injury were recorded for patients that developed PVR. Zones of injury are defined by whether the injury is an open globe or closed globe injury and based on the anatomic location of the eye injury.²⁴ Closed globe zone 3 injuries were noted in eight eyes (10.5%). Eight eyes (10.5%) had open globe zone 1, 12 (15.8%) had open globe zone 2, and 48 (63.2%) had open globe zone 3 injuries. Of the open globe injuries, six were penetrating injuries, 36 were from

intraocular foreign bodies (IOFBs), 12 were from perforating injuries, and 14 were from globe ruptures.

Visual Acuity and Ocular Trauma Score

OTS and initial and final VA were recorded, as shown in Table 1. In the database, four patients (5.3%) were missing final data, and five (6.6%) patients were initially intubated. Twenty-three eyes (30.3%) had no change in VA grade, 31 (40.8%) improved, and 13 (17.1%) declined.

To evaluate the importance of PVR relative to other risk factors for final VA less than 20/200, a multivariate analysis was completed on all non-enucleated eyes in the WROTD (Table 2). This analysis studied whether patients had a final VA of grades 1 to 2 (20/200 or better vision) or grades 3 to 5 (19/200 or worse vision) from six features: PVR, RD, perforating injury, globe rupture, optic nerve injury, and phthisis. The OTS was used as the basis for variable selection with RD, globe rupture and perforating injury included as they are part of the OTS. Since afferent pupillary defect (APD; component of OTS) was frequently recorded by a non-ophthalmologist and

TABLE 3A
Univariate Analysis to Assess for Risk Factors the Development of PVR in all Patients
(n = 76)

Variable	Number of Eyes With Injury	Odds Ratio	95% CI	P Value
IOFB	44	7.6	4.5-12.9	< .001
VH	59	9.9	5-21.2	< .001
Comotio	16	1.8	0.9-3.3	.08
CrRupt	18	3.7	1.9-6.9	< .001
SRHeme	37	6.6	3.8-11.3	< .001
IRHeme	31	5	2.9-8.6	< .001
MacHeme	26	6.7	3.7-12.02	< .001
ChorHeme	37	8.3	4.8-14.3	< .001
ChorRupt	7	2.8	0.99-6.8	.03
MacHole	4	2	0.5-6.2	.3
RT	45	8.3	4.8-14.6	< .001
RD	52	15.8	8.9-28.5	< .001
Associated systemic injury	63	0.8	0.42-1.64	.49
Neurologic injury	19	0.79	0.43-1.38	.43
Extremity injury	37	1.06	0.65-1.76	.81

IOFB = intraocular foreign body; VH = vitreous hemorrhage; CrRupt = chorioretinal rupture; SRHeme = subretinal hemorrhage; IRHeme = intraretinal hemorrhage; MacHeme = macular hemorrhage; ChorHeme = choroidal hemorrhage; ChorRupt = choroidal rupture; MacHole = macular hole; RT = retinal tear; RD = retinal detachment; Mac = macula

likely unreliable, optic nerve injury was selected instead. Endophthalmitis, another variable in the OTS, was not included as it was very rare in the WROTD. However, phthisis was included as it was a cause of blindness in the WROTD. PVR was found to be a significant risk factor for a poor final VA ($P < .001$).

Associated Injuries and Surgeries

The following associated injuries were assessed in eyes that developed PVR. Twenty-three (30.3%), 22 (28.9%), and 33 (43.4%) eyes had either one or more corneal, corneoscleral, or scleral lacerations, respectively. A vitreous hemorrhage was seen in 59 (77.6%) eyes. Commotio was noted in 16 eyes (21.1%), chorioretinal rupture was noted in 18 eyes (23.7%), subretinal hemorrhage was noted in 37 eyes (48.7%), intraretinal hemorrhage was noted in 31 eyes (40.8%), and macular hemorrhage was also found in 26 eyes (34.2%). Retinal tears were seen in 45 eyes (59.2%) of patients. RDs were documented in 52 eyes (68.4%). Of these eyes, 45 had a known macula status, with macula-on detachments in nine and macula-off detachments in 36. Choroidal hemorrhage was noted in 37 eyes (48.7%). Further, 31 eyes (40.8%) of patients developed phthisis.

Many patients suffered severe neurologic and orthopedic injuries from improvised explosive device blasts. Systemic neurologic injuries such as cerebral vascular accidents, anoxic brain injury, or spinal cord injury were noted in 19 patients (25.0%), traumatic brain injury in 31 (40.8%), and extremity injury in 36 (47.3%).

In the eyes that had PVR but did not have a documented RD ($n = 24$), 22 were open globe injuries. Nineteen eyes had a documented IOFB, 17 had a vitreous hemorrhage, and six had a retinal tear. Of the two eyes with closed globe injuries, one had a vitreous hemorrhage with chorioretinal rupture and underwent pars plana vitrectomy (PPV) and pars plana lensectomy; the other eye had noted intraretinal hemorrhage and cataract formation and underwent pars plana lensectomy.

Regarding surgical intervention, 70 eyes (92.1%) underwent a PPV and 15 (19.7%) eyes of patients had a scleral buckle. Moreover, five eyes (6.6%) underwent a subsequent enucleation. Tamponade use was recorded: 38 eyes were filled with silicone oil, 17 with C_3F_8 , five with SF_6 , and three with air. Seven had undocumented tamponade selection. Time to initial retina surgery was available in only 41 patients,

TABLE 3B
Univariate Analysis for Risk Factors the Development of PVR in Patients With Retinal Detachment (n = 52)

Variable	No. of Eyes With Injury	Odds Ratio	95% CI	P Value
IOFB	25	7.6	4.5-12.9	< .001
VH	42	0.8	0.3-2.3	.6
Commotio	15	2.4	0.9-6.3	.05
CrRupt	16	2.3	0.9-5.6	.05
SRHeme	30	2	0.9-4.4	.07
IRHeme	26	2	0.98-4.6	.05
MacHeme	21	2.2	0.98-5	.04
ChorHeme	33	1.2	0.5-2.7	.7
ChorRupt	7	2.9	0.7-12.2	.1
MacHole	4	1.2	0.3-5.7	.7
RT	39	0.8	0.3-2.4	.8
Unsuccessful repair	21	5.9	1.6-25	.002
Mac on vs. off	9 Mac off 36 Mac on			.5
Associated systemic injury	42	0.53	0.19-1.54	.22
Neurologic injury	15	0.86	0.37-1.93	.85
Extremity injury	25	1.16	0.54-2.47	.72

IOFB = intraocular foreign body; VH = vitreous hemorrhage; CrRupt = chorioretinal rupture; SRHeme = subretinal hemorrhage; IRHeme = intraretinal hemorrhage; MacHeme = macular hemorrhage; ChorHeme = choroidal hemorrhage; ChorRupt = choroidal rupture; MacHole = macular hole; RT = retinal tear; RD = retinal detachment; Mac = macula

and the time to surgery on average was 22.56 days (range: 3 to 87 days). Thus, time to vitreoretinal surgery was not included in statistical analysis. In addition of those that underwent retinal surgery for RD, 21 of 41 patients (51.2%) had a successful reattachment.

Risk Factors for PVR Development

A further statistical analysis using univariate analysis was completed to review risk factors for the development of PVR in all patients and those with RD as described in the methods section. In all patients with PVR, there were multiple different significant risk factors (Table 3A). In patients with RD, IOFB ($P < .001$), unsuccessful repair ($P = .002$), and macular hemorrhage ($P \leq .04$) were identified as significant risk factors (Table 3B)

DISCUSSION

This study sought to examine the risk factors associated with the development of PVR in globe injury after combat ocular trauma in U.S. service members. This is a unique patient populace due to severity of injury as evidenced by more than 70% of patients

having an OTS less than 65 portending a poor visual prognosis.²² The more severe the trauma experienced by the eye, the more likely the development of PVR is to occur.¹⁰ Ocular trauma has a high rate of development of PVR, secondary to the subsequent inflammatory cascade, breakdown of the blood-ocular barrier, and direct introduction of cells from outside the eye.^{10,13} In patients with ocular trauma and/or RD, there is a risk of retinal hypoxia and apoptosis of photoreceptor cells.^{5,25-27} The combination of inflammation, ischemia, and blood further activates inflammatory cells resulting in the release of cytokines and growth factors.¹⁰ When these proteins interact with the retinal pigment epithelium (RPE), glial and Müller cells, it results in their proliferation. Particularly in RPE cells, their interaction with vitreous cytokines results in an epithelial to mesenchymal transformation allowing migration into the vitreous.^{28,29} RPE and/or Müller cells that transitioned into intravitreal fibroblasts along with extraocular fibroblasts introduced via trauma transdifferentiate into myofibroblasts.³⁰ These myofibroblasts result in the contraction of cellular membranes pulling on the vitreous

and in patients with RD this can prevent the retina from healing and reattaching.^{10,31}

PVR results in a worse prognosis.^{14-17,33-33} In the WROTD, approximately 30% of ocular injuries had a final VA of less than 20/200, but in patients with PVR, approximately 80% had a final VA less than 20/200.²¹ As such, in our study, PVR development was found to be positively associated with a final VA less than 20/200 ($P < .001$) in multivariate analysis.

High myopia,³⁴ open globe injuries,^{9,35} and vitreous hemorrhage^{9,36} have all been found in previous studies to be risk factors for the development of PVR. In our study, there were multiple risk factors characteristic of both closed and open globe injuries. However, critically associated injuries ($P = .49$) were not risk factors. Patients with more severe systemic injuries may not be at an increased risk for PVR, although this will require further study.

In patients with a RD, suffering an injury from an IOFB resulted in an increased risk for developing PVR ($P < .001$). Trauma related to IOFB onset remains a significant complication for future PVR development.³⁷⁻⁴¹ In a previous study from the WROTD⁴¹ the risk factors for the development of PVR in patients with an IOFB injury were studied. In this study of all IOFBs in the WROTD,⁴¹ not just IOFBs in patients with RD as in the current study, IOFBs were not associated with a poor final visual outcome less than 20/200. An increased risk for development of PVR was noted in OTS 0 to 65 injury ($P < .001$), RD ($P < .001$), subretinal hemorrhage ($P = .001$), macular hemorrhage ($P = .001$), and posterior zone of injury ($P = .002$). For total number of IOFB ($P = .97$), volume of the largest IOFB per eye ($P = .02$) and length of time to removal ($P = .11$), there was not a significant associated risk with PVR development.

The timing of vitreoretinal surgical intervention after globe trauma is highly controversial. A recent systematic review of trauma in the civilian population looked at the timing of outcomes of vitreoretinal surgery after traumatic RD and found mixed results in regard to early (less than 7 days) intervention versus greater than 7 days surgical intervention.¹ The rate of PVR in the review varied with those who had repair in less than 7 days ranging from 39% to 44%, whereas in those who had repair more than 7 days later was 5% to 56%. Another study in a civilian population found that if the interval of injury and vitrectomy was greater than 28 days there was a large risk for PVR development (odds ratio: 139.25; 95% CI, 1.13-6.52).³⁵ A recent randomized, controlled study looking at vitrectomy in patients with open globe injuries, found that patients that underwent early vitrectomy (less than 4 days) versus delayed vitrectomy (10 to 14

days) had greater visual improvement (gain of 3 lines; 38 vs. 12%; $P = .041$) and lower rates of PVR (14 vs. 40%; $P = .054$).⁴² This study found no significant difference in the rate of RD between the two groups (86 vs. 88%; $P = 1.0$).⁴² In our study as discussed above, unfortunately only two-thirds of patients had a documented time to surgery making statistical analysis of this factor challenging. Our military populace is very different than the standard RD populace in that all are secondary to trauma, whereas in the civilian populace, only approximately 1% of RD is related to trauma.⁴³ The patient population in our study is also highly unique as it is a young male population with serious injuries as evidenced by approximately 70% of eyes having an OTS score less than 65. These differences make comparisons between military and civilian trauma inappropriate, therefore making assumptions about timing for surgery based off military experience difficult.

A previous study found that macula-off RD is over four times more likely to lead to the development of PVR;⁴⁴ however, in our study, macular status was not shown to be a significant risk factor for PVR development ($P = .5$). However, macular hemorrhage was found to be a significant risk factor for the development of PVR ($P = .04$). It is unclear to the authors why macular hemorrhage versus subretinal or intraretinal hemorrhage elsewhere in the retina was a risk factor for the development of PVR, and further study is needed. It is likely that the subretinal or choroidal hemorrhage was very large in these patients and included the macula but was not isolated to the macula like a subretinal neovascular membrane.

Thus, from a military perspective, if consideration for vitreoretinal surgery in a war zone becomes necessary, it is critical that the best supplies and equipment are available to manage these patients to ensure the best possibility of surgical reattachment. In our clinical practice, eyes that are at greatest risk for PVR formation — notable retinal detachment, presence of IOFB, and hemorrhage inclusive of the macula justify more urgent evacuation to mitigate the likelihood of PVR formation. Of note, these scenarios — specifically the presence of sub-macular hemorrhage — reduce visual prognosis, as well. That said, earliest possible vitreoretinal intervention must be considered in all cases of posterior segment trauma to minimize the likelihood of PVR formation. In future wars, if longer evacuations are anticipated have a vitreoretinal surgeon at a CSH or closer to the combat theater, such as at LRMC, may be necessary to ensure best patient outcomes.

Some vitreoretinal surgeons have proposed ophthalmic or systemic immunosuppressive or anti-in-

flammatory medications as an adjunct therapy to manage proliferative vitreoretinopathy.⁴⁵⁻⁴⁸ Although these treatments show promise, during the study period, they were generally not considered given the complex injury patterns suffered by the patients. Injuries typically included both anterior and posterior segment trauma, as well as significant systemic injuries. Anecdotally, we rarely used medications such as intravenous or oral steroids as a surgical adjunct in isolated cases. However, these cases were typically the most severe injuries, and any data analysis would be skewed by the severity of the injuries employed. Moreover, we did not collect use of adjunct medications such as periorbital or systemic steroid usage or triamcinolone use during vitrectomy as variables in our dataset.

There were multiple limitations to this study. Early in OIF and OEF, there were no electronic health records making patient tracking from site of injury to WRAMC difficult. At times, the records were incomplete making data analysis complicated. In addition, initial VA were first taken when the patients were extubated, and this could have been multiple days after injury and/or surgery; thus, making OTS and initial VA outcomes difficult to evaluate. In addition, approximately 40% of patients had a traumatic brain injury making the initial visual acuity data potentially unreliable. Another critical limitation is that only 41 patients had a documented time to surgery, thus making it difficult to complete statistical analysis on the data related to timing of surgery. Lastly, it is possible that PVR developed in some patients prior to first intervention, however this was not recorded in the database.

To conclude, this paper represents a unique series of U.S. service members sustaining eye injuries with delayed initial RD repair (time to surgery was 22.56 days; range: 3 to 87 days). PVR is a common complication in combat ocular trauma occurring in nearly 10% of injured patients evacuated to WRAMC. Risk factors for PVR development varied and were characteristic of both open and closed injuries. In patients with RD, it is critical to ensure a successful reattachment. IOFB is a significant risk factor for subsequent development of PVR. Finally, nearly 80% of these patients had a final VA less than 20/200, and PVR is a significant cause of blindness in deployed U.S. service members with ocular trauma.

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Lateral Canthotomy and Cantholysis in Operations Iraqi Freedom and Enduring Freedom: 2001–2011

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Purpose: To describe outcomes and associated ocular injuries of lateral canthotomy and cantholysis (LCC) as performed in combat ocular trauma.

Methods: Data from the Walter Reed Ocular Trauma Database of patients requiring LCC during Operations Iraqi Freedom and Enduring Freedom was reviewed as a retrospective cohort. Primary outcome measures included final visual acuity (VA) and Ocular Trauma Score. Secondary outcome measures were associated injuries and timing of surgery.

Results: Thirty-six LCCs were recorded on a total of 890 eyes (4.04 %) in the Walter Reed Ocular Trauma Database. Eighteen out of 36 eyes (50.00%) had a final VA of the affected eye of 20/200 or worse vision. From the initial available VA measured either at the time of injury or at Walter Reed Army Medical Center, 13 eyes (40.63%) had no change in VA, 15 eyes (46.88%) had improvement, and 4 (12.5%) had a decrease in VA (n = 32, data unavailable for 4 eyes). Ocular Trauma score 0–65 was noted in 14 (38.9%) and 66–100 (61.1%). Retinal detachment (6, 16.67%), optic nerve injuries (7, 19.44%), orbital fractures (20, 55.56%), and retrobulbar hematoma (25, 69.44%) were commonly associated injuries. Of the 36 LCC, 18 (50.00%) were performed as the first surgery performed at the combat support hospital, 13 (36.11%) as the second, 4 (11.11%) as the third, and 1 (2.78%) as the fourth.

Conclusions: The largest subgroup of patients had an improvement in VA associated with performance of LCC; however, half of patients remained with a final VA of equal to or worse than 20/200 due to severe ocular trauma.

(*Ophthalmol Plast Reconstr Surg* XXX:XX:00–00)

The evolution of the recent warfare during Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF) has increased the rate of ocular injuries as compared to past wars.¹ Between 2002 and 2007 during OIF and OEF, 13% of patients suffered ocular battlefield injuries.^{1–3} Increasingly evident is the necessity for oculoplastic intervention, to include lateral canthotomy and cantholysis (LCC), in combat blast injuries, which predominated in OIF and OEF.¹ Previous research is lacking from OIF and OEF; earlier studies have reported that rates between 4% and 15%^{4,5} of all ophthalmologic surgical patients underwent LCC.

Ocular compartment syndrome (OCS) threatens sight in as little as 60 minutes and requires emergent intervention.^{6–8} Most commonly, OCS is a result of retrobulbar hemorrhage (RBH).^{9,10} To release the pressure from OCS, regardless of etiology, LCC is the definitive treatment and needs to be performed promptly to prevent permanent damage to sight.¹¹ Patients who require emergent interventions, such as LCC, often suffer additional ophthalmologic injuries that portend a worse visual outcome.^{1,4,12} Careful analysis of these injuries and interventions can lead to improved protective and preventative measures. The authors reviewed eyes of US Soldiers and Department of Defense Civilians who underwent LCC and were evacuated from Iraq (OIF) and Afghanistan (OEF) to Walter Reed Army Medical Center (WRAMC) from 2001 to 2011. Although earlier studies have reported the rate of LCC in combat ocular trauma, this study fills the gaps in the literature by further presenting the outcomes of patients who had an LCC due to combat trauma.

METHODS

Retrospective case series data (2001–2011) from American Soldiers or Department of Defense civilians injured in OIF or OEF and evacuated to WRAMC was collected into the Walter Reed Ocular Trauma Database (WROTD). WROTD was approved by the Institutional Review Board at WRAMC and Walter Reed National Military Medical Center. The scope of WROTD extends from the initial assessment and treatment by ophthalmologists at respective Combat Support Hospitals to evacuation to WRAMC. Patient inclusion was based on patient records, transfer summaries, and operative reports. The data from these patients was collected on Microsoft Excel (Microsoft Corporation, Redmond, WA), housed on SPSS (IBM, New York), and then R statistical software (R Foundation for Statistical Computing, Vienna, Austria) was used for data and statistical analysis. Data was collected with a HIPAA-complaint method. Further description of the data collection of the WROTD is outlined in previous studies.^{1,4,13}

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Inclusion criteria were ocular injuries leading to LCC. Exclusion criteria were ocular injuries of non-Department of Defense civilian trauma or injury outside of a combat zone. Primary outcome measures included final visual acuity (VA) and the relationship to ocular trauma score (OTS) as a predictor of prognosis. Secondary outcome measures included use of eye protection, associated eye injuries, source of injury, and additional surgical procedures performed. When the patients were first awake, initial VA was assessed. Frequently, VA was not or could not be tested until they had arrived at WRAMC or after initial surgery. Per protocol, the post-injury VAs were tested at the time range of 20 to 50 days post-injury, 50 to 200 days post-injury, and the last documented VA date. Using the Birmingham Eye Trauma Terminology by Kuhn et al., eyes were classified by injury type.^{14,15}

RESULTS

Thirty-six LCCs were recorded out of a total of 890 eyes (4.04%) in the WROTD. Thirty patients required unilateral LCC. The average age of the patients was 25.17 (range 19–47). Thirty-three (97.06%) patients were male. Twenty-nine patients (85.29%) were injured in Iraq, and 5 patients (14.70%) were injured in Afghanistan. Twenty-six (76.47%) patients were members of the Army, 3 (8.82%) patients were members of the Army National Guard, 1 (2.94%) patient was a member of the Air Force, 1 (2.94%) patient was a member of the Marines, and 3 (8.82%) patients' branch of service was unknown.

Twenty-seven eyes (75.00%) were injured from an improvised explosive device including the 2 patients requiring bilateral LCC, 5 eyes (13.89%) were injured by rocket-propelled grenade, 1 eye (2.78%) was injured by motor vehicle accident, 2 eyes (5.56%) were injured by gunshot wound, and 1 eye (2.78%) was injured by mortar. Six (16.67%) eye injuries occurred in patients who did not wear eye protection, 10 injuries (27.78%) occurred in patients wearing eye protection, and 20 eyes (55.56%) had undocumented eye protection adherence including those of the 2 patients requiring bilateral LCC.

Visual acuity and OTS results are summarized in Tables 1 and 2. Thirty-two of 36 eyes had initial and final VA documented and thus met criteria for analysis. Thirty eyes (83.33%) suffered a globe injury. While many patients suffered bilateral globe injuries, only one patient suffered bilateral globe injuries that required bilateral LCC. Of the open globe injuries ($n = 14$), as summarized by Table 3, 2 suffered from a globe rupture and 4 suffered a perforating injury. Retinal detachment, optic

nerve injuries, orbital fractures, and RBH OTS Grades and VA changes are documented in Table 3.

The priority of LCC and other ophthalmic surgeries performed at the Combat Support Hospitals or Landstuhl Regional Medical Center were recorded (Table 4 and Figure). All OTS Grade 1 and 5 eyes had LCC performed as the primary surgery and did not require additional procedures during evacuation.

DISCUSSION

Ocular injuries from modern warfare increase the importance of emergent vision-saving interventions. OCS, like other compartment syndromes, is linked to significant morbidity and requires prompt intervention as it can quickly compromise vision from ischemia of the optic nerve and retina. RBH is the most common cause of OCS, but other common sequela of nonocular trauma, including burns, inflammation, massive fluid resuscitation, abscesses, and cellulitis, can result in OCS. Traumatic RBH has a demonstrated risk of permanent vision loss in patients presenting with decreased VA of 44% to 52%.^{16–18} The diagnosis of OCS is largely clinical, especially in the pre-hospital setting with limited resources.

To protect VA, orbital compartment syndrome requires prompt clinical diagnosis and surgical decompression.^{11,19–24} Severing the lateral canthal tendon and releasing the inferior limb from its bony insertion immediately decreases intraocular pressure.^{25–27} LCC is an efficacious surgical technique to relieve intraocular pressure that threatens permanent damage to vision through revascularization of the compromised tissues.^{19,26,28} The time to retinal infarct is approximately 60 to 120 minutes at intraocular pressure above 40 mm Hg.^{6–8,18,29,30} LCC within 2 hours provides maximum benefit.^{18,27,31–33} Although in severe injuries there may not be improvement in final VA, if a provider suspects OCS, he or she should perform LCC quickly even in an austere prehospital environment to provide maximal chance of VA preservation. In our article as demonstrated in Table 4, although statistical analysis was not performed, there was general trend toward improved change in VA when LCC was performed as the primary procedure. However, these patients tended to have less severe OTS scores compared to those who had it performed as a secondary

TABLE 1. Ocular trauma score grades and the relationship between ocular trauma score and change in visual acuity

OTS grade	Number of eyes	Change in VA*	OTS*
Grade 5 (91–100)	6 (16.67%)	Improved (15, 46.88%)	Grade 5 (5, 33.33%)
Grade 4 (81–90)	3 (8.33%)		Grade 4 (2, 13.33%)
Grade 3 (66–80)	6 (16.67%)		Grade 3 (4, 26.67%)
Grade 2 (45–65)	8 (22.22%)		Grade 2 (3, 20.00%)
Grade 1 (0–44)	7 (19.44%)		Grade 1 (0)
Adnexal Injury	6 (16.67%)	No change (13, 40.63%)	Adnexal (1, 6.67%)
			Grade 5 (2, 15.38%)
			Grade 4 (0)
			Grade 3 (0)
			Grade 2 (4, 11.11%)
		Decreased (4, 12.50%)	Grade 1 (5, 38.46%)
			Adnexal (2, 15.38%)
			Grade 5 (0)
			Grade 4 (0)
			Grade 3 (2, 50.00%)
			Grade 2 (1, 25.00%)
			Grade 1 (1, 25.00%)
			Adnexal (0)

* $n = 32$, 4 eyes excluded for not meeting criteria.

OTS, ocular trauma score; VA, visual acuity.

TABLE 2. Visual acuity grades

VA	VA grade	Initial VA grade (number of eyes)	Final VA grade (number of eyes)
No light Perception	Grade 5	6 (16.67%)	10 (27.78%)
Light perception	Grade 4	9 (25.00%)	6 (16.67%)
Hand motion			
Count fingers	Grade 3	4 (11.11%)	2 (5.56%)
20/800			
20/400			
20/200	Grade 2	6 (16.67%)	2 (5.56%)
20/100			
20/80			
20/70			
20/60			
20/50			
20/40	Grade 1	8 (22.22%)	15 (41.67%)
20/30			
20/25			
20/20			
20/15			
Unknown	Unknown	3 (8.33%)	1 (2.78%)

VA, visual acuity.

TABLE 3. Associated injuries: ocular trauma score and change in visual acuity

	Retinal detachment	Optic nerve injuries*	Orbital fractures†	Retrobulbar hemorrhage‡§	Total open globe injuries¶	Globe rupture	Perforating injuries
Number of patients (n = 36)	6, 16.67%	7, 19.44%	20, 55.56%	25, 69.44%	14, 38.89%	2, 5.56%	4, 11.11%
Grade 5	0	1, 16.67%	3, 17.65%	3, 15.79%	0	0	0
Grade 4	0	0	2, 11.76%	3, 15.79%	0	0	0
Grade 3	0	1, 16.67%	4, 23.53%	5, 26.32%	2, 15.38%	0	0
Grade 2	3, 50.00%	2, 33.33%	4, 23.53%	3, 15.79%	5, 38.46%	0	1, 25.00%
Grade 1	3, 50.00%	2, 33.33%	4, 23.53%	5, 26.32%	6, 46.15%	2, 100%	3, 75.00%
Improvement in VA	2, 33.33%	2, 33.33%	8, 47.06%	11, 52.38%	3, 23.08%	0	0
No change in VA	3, 50.00%	2, 33.33%	6, 35.29%	7, 33.33%	8, 61.53%	1, 50.00%	4, 100.00%
Decreased VA	1, 16.67%	2, 33.33%	3, 17.65%	3, 14.29%	2, 15.38%	1, 50.00%	0

*n = 6, 1 patients of 7 excluded for not meeting criteria.

†n = 17, 3 patients of 20 excluded for not meeting criteria.

‡n = 19 for OTS analysis, 6 patients of 25 excluded for not meeting criteria.

§n = 21 for VA analysis, 4 patients excluded from 25 for not meeting criteria.

¶n = 13, 1 patient of 14 excluded for not meeting criteria.

OTS, ocular trauma score; VA, visual acuity.

TABLE 4. Lateral canthotomy and cantholysis surgical priority: ocular trauma score and change in visual acuity

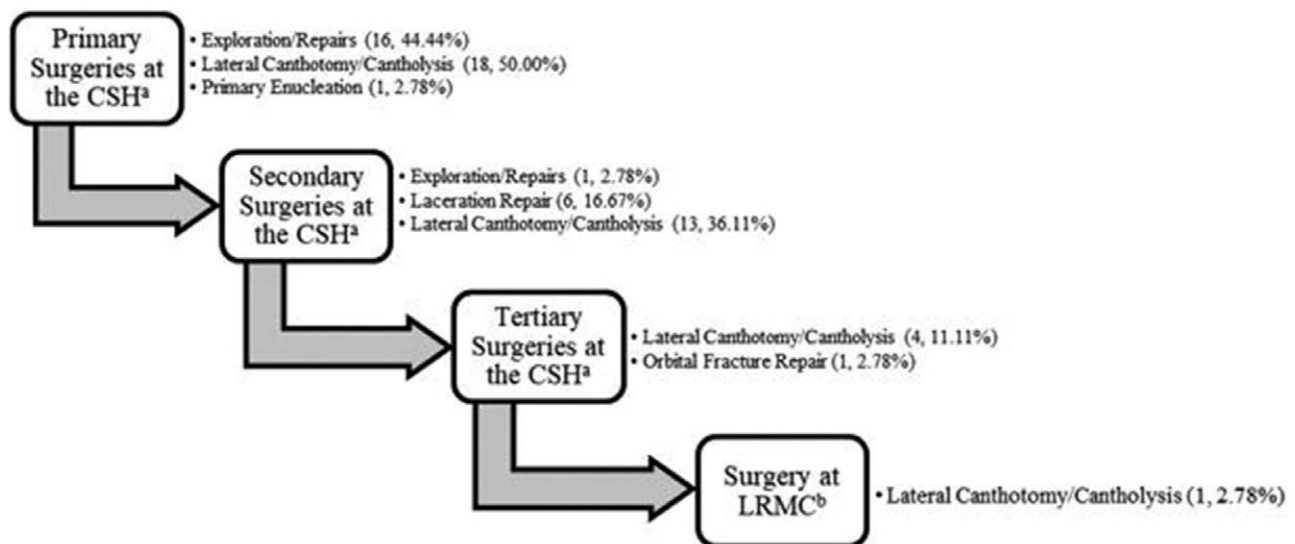
	Performed as a primary procedure*†	Performed as a secondary procedure‡	Performed as a tertiary or quaternary procedure
Number of patients (n = 36)	18, 50.00%	13, 36.11%	5, 13.89%
Grade 5	6, 46.15%	1, 8.33%	0
Grade 4	2, 15.38%	0	1, 20.00%
Grade 3	3, 23.08%	2, 16.67%	1, 20.00%
Grade 2	2, 15.38%	3, 25.00%	3, 60.00%
Grade 1	0	6, 50.00%	0
Improvement in VA	8, 53.33%	5, 41.67%	2, 40.00%
No change in VA	2, 13.33%	6, 50.00%	2, 40.00%
Decreased VA	5, 33.33%	1, 8.33%	1, 20.00%

*n = 13 for OTS analysis, 5 excluded of 18 for not meeting criteria.

†n = 15 for VA analysis, 3 excluded of 18 for not meeting criteria.

‡n = 12 for OTS and VA analysis, 1 excluded of 13 for not meeting criteria.

OTS, ocular trauma score.



Lateral canthotomy and cantholysis and associated surgeries. ^aCSH, Combat Support Hospital. ^bLPMC, Landstuhl Regional Medical Center.

procedure likely due to severe life-threatening injuries that lead to a delay in the performance of the procedure.

There is little previous research analyzing LCC during OIF and OEF. However, a single study found that about 15% of all OIF ophthalmologic surgical patients required LCC.⁵ In our study, only 4.04% of all patients evacuated to WRAMC with ocular injuries underwent a LCC. Both cohorts are small and lend themselves to sampling bias. In addition, the former study reviewed patients with craniomaxillofacial trauma using the JROTD, and similarly to the WROTD, LCC was not a primary variable measured.

OTS is used to predict visual outcomes after open globe injuries, with accuracy of approximately 80%.^{11,34} Previous studies correlate a lower OTS score with a worse VA outcome.^{34–36} OTS is calculated by using the initial VA and adjusting for concomitant injuries or exam findings.³⁷ OTS is the only predictive system for ocular trauma; however, it has never been validated by a prospective study.³⁸ Globe injuries tended to be extensive with many patients sustaining injuries posteriorly behind the muscle insertions, indicating that in the analyzed cohort, injuries were severe. Despite the evidence of extensive ocular injury, the majority (87.50%) of eyes showed improved or no change in VA. As many of the injured patients suffered multiple ocular injuries or generalized polytraumas, it is difficult to surmise that LCC is the sole reason that these patients had good outcomes.

While the WROTD cannot speak to the clinical indications providers used to decide to perform LCC, only 25 eyes (69.44%) had documented RBH. While OTS was nearly equally spread between Grades 1 to 5, the majority (52.38%) of RBH LCC eyes had improved VA. Of note, all but one eyes with RBH suffered an orbital wall fracture. The remaining associated injuries occurred in small numbers, making it difficult to surmise conclusions.

There were several limitations to this study. The recording of LCC was not a primary or secondary outcome recorded in the WROTD but rather a subgroup measured within an outcome. In addition, the WROTD is a retrospective review. The WROTD population is a generally healthy younger demographic with required regular medical follow-up. Previously, Dalley et al.³⁹ demonstrated that younger healthy OCS patients have better recovery, skewing the data toward the propensity of good prognosis. Some of the data is incomplete, due to time

restrictions in an unstable patient, incomplete recording, or the consciousness level of the patient. Data on time of injury to initial VA performed is largely absent, making it difficult to ascertain accuracy of change in VA and calculating OTS. Time to relief of orbital compartment pressure by LCC is proportional to outcomes.^{6–8,40} However, the time to LCC is poorly recorded. Additionally, the patients during OIF and OEF not evacuated to WRAMC are not included in the analysis. Finally, statistical analysis was performed, but only on a small number of patients, and thus care should be taken in review of significance.

In conclusion, this study demonstrates a few key points. Patients undergoing LCC for modern ocular combat trauma commonly have associated ocular injuries, especially RBH and orbital fractures. Even though many patients suffered extensive eye trauma, many eyes did not demonstrate decreased VA after LCC ($n = 28$, 87.50%). However, due to the severity of the trauma with commonly associated retinal detachments and optic nerve injuries, half of the patients had a final VA less than 20/200.

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Orbital Fractures and Associated Ocular Injuries in Operation Iraqi Freedom and Operation Enduring Freedom Referred to a Tertiary Care Military Hospital and the Effect on Final Visual Acuity

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Purpose: To update the incidence of orbital fractures in U.S. Soldiers admitted to the former Walter Reed Army Medical Center from 2001 to 2011 after sustaining combat injuries in Operation Iraqi Freedom and Operation Enduring Freedom.

Methods: Data were collected in the Walter Reed Ocular Trauma Database. Inclusion criteria were any U.S. Soldier or Department of Defense civilian with an orbital fracture injured in Operation Iraqi Freedom/Operation Enduring Freedom. Primary outcome measures were final visual acuity and the effect of orbital fracture, number of fractures, and anatomic location of fracture on final visual acuity.

Results: Eight-hundred ninety eye injuries occurred in 652 patients evacuated to Walter Reed Army Medical Center between 2001 and 2011. Orbital fractures occurred in 304 eyes (34.2%). A single wall was fractured in 140 eyes (46.05%), 2 in 99 (32.6%) eyes, 3 in 31 (10.2%), 4 in 28 (9.2%), and unknown in 6 (1.9%) eyes. Roof fractures were found in 74 (24.34%), medial wall in 135 (44.41%), lateral wall in 109 (35.9%), and floor fractures in 217 (71.4%). Final visual acuity was analyzed and 140 (46.05%) eyes had greater than 20/40 vision, 17 (5.59%) were 20/50 to 20/200, 26 (8.5%) were count fingers to light perception, and 95 (31.3%) were no light perception. In logistic regression analysis, roof ($p = 0.001$), medial ($p = 0.009$), and lateral fractures ($p = 0.016$) were significantly associated with final visual acuity less than 20/200, while floor fractures were not ($p = 0.874$). Orbital fracture and all fracture subtypes were

significantly associated with traumatic brain injury, retrobulbar hematoma, optic nerve injury, but not for vitreous hemorrhage, commotio, hyphema, and choroidal rupture. Fracture repair was noted in 45 (14.8%).

Conclusions: Orbital fractures occurred in a third of Operation Iraqi Freedom/Operation Enduring Freedom eyes of ocular trauma patients referred to one tertiary care military hospital. This resulted in approximately 40% of these eyes remaining legally blind after injury.

(*Ophthalmic Plast Reconstr Surg* 2020;36:55–60)

In Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF), ocular injuries were the fourth most common injury behind amputation, traumatic brain injury, and posttraumatic stress disorder.¹ Eye injuries were present in 13% of all casualties evacuated from OIF/OEF.² Previously reported rates of orbital fractures during OIF and OEF have ranged from approximately 12% to 35%.^{2–5} Multiple studies^{6–10} have shown a general decrease in visual acuity (VA) in patients with orbital fracture. However, studies^{7,11} with formal VA measurements are generally lacking. In this retrospective study, the authors' review the effect of orbital fracture itself. In addition, the authors' studied the anatomic location and number of walls fractured upon final VA to better review visual prognosis. Finally, orbital fracture and subtypes based on number and location of fracture, and their relationship to various associated complications were reviewed.

MATERIALS AND METHODS

The Walter Reed Ocular Trauma Database (WROTD) is a collection of data from service members who sustained eye injuries during OIF and OEF between 2001 and 2011. The WROTD was developed under a protocol approved by the Institutional Review Board at Walter Reed Army Medical Center (WRAMC). In addition, this study was Health Insurance Portability and Accountability Act of 1996-compliant. Although the database does not represent all ocular injuries in OIF/OEF during this period, the majority of the ocular injuries were captured as most of non-burn patients were evacuated to WRAMC. Burn patients were referred to San Antonio Military Medical Center. After initial trauma in Iraq or

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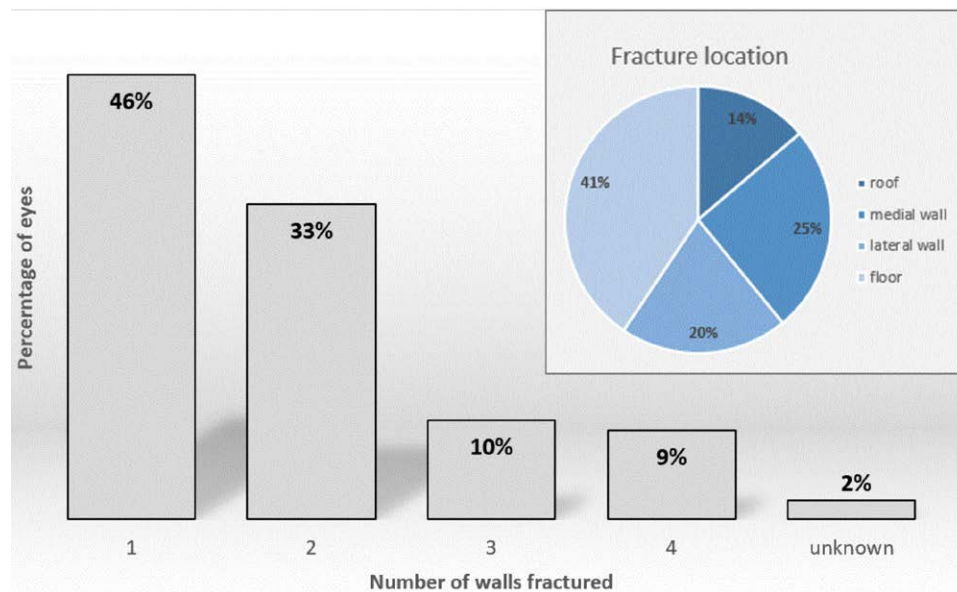
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Location and number of fractures.

Afghanistan, patients were transferred from the site of injury to Landstuhl Regional Medical Center in Landstuhl, Germany to WRAMC. Data were collected from initial ocular evaluation in Iraq or Afghanistan, transfer summaries, operative reports, and outpatient records. The data were initially gathered in Microsoft Excel (Microsoft Corporation, Redmond, WA, U.S.A.) and then transferred to statistical software (STATA 14.0, College Station, TX, U.S.A.) for data analysis. Further description of the collection of the data in the WROTD is outlined in previous articles.^{2,12,13}

Inclusion criteria were any U.S. Soldier or Department of Defense civilian injured in OIF/OEF with an orbital fracture. Primary outcome measures were final VA and the effect of orbital fracture, number of fractures, and anatomic location of fracture on final VA. Secondary outcome measures included the effect of orbital fracture, number of fractures, and anatomic location of fracture on associated eye injuries including retinal detachment, retrobulbar hemorrhage, hyphema and traumatic brain injury, and Ocular Trauma Score (OTS).

Injuries and zone of injury were classified as described by Birmingham Eye Trauma Terminology^{14–16} and OTS were calculated as described by Kuhn et al.¹⁷ OTS raw points were converted into categories ranging from 1 to 5, with category 1 having the worst prognosis and 5 having the best prognosis. Snellen visual acuities were converted to vision grades for statistical analysis.^{2,13} Grade 1 was defined as 20/40 or better, grade 2 was 20/50 to 20/200, grade 3 was 19/200 to 1/200, grade 4 was hand motion or light perception, and grade 5 was no light perception. For the entire dataset (n = 890), 99 patients were lacking an initial recorded VA

and of these 55 were intubated. Per protocol, VA was collected from initial assessment or when patients were initially awake, 20 to 50 days postinjury, 150 to 200 days postinjury and the last documented VA date; however, in many cases only the initial and final VA were recorded.

Statistical Analysis. Univariate analysis was completed using Fisher exact test for categorical variables and the Wilcoxon rank sum test with continuity correction for continuous variables. Odds ratios and 95% CIs given for categorical variables were also computed via Fisher's method. For proportions and incidence rates, the Agresti and Coull¹⁸ method was used to calculate CIs. Multivariate analysis was completed using binomial logistic regression; significance was assessed using the type 3 likelihood ratio test as implemented in the "car" package.¹⁹ Univariate and multivariate analyses discarded cases with missing information and analyzed records in which none of the variables tested in that analysis had missing values; proportions and incidence rates counted the total number of positive incidences over the total number of eyes in the set. Alpha was set at 0.05 for all analyses.

RESULTS

Demographics. Three-hundred four (34.2%) orbital fractures occurred out of 890 eyes in the WROTD (Fig.). The average age was 27.7 ± 7.4 with a range of 18 to 53 years old. Two-hundred ninety-eight injuries (98.0%) occurred in male patients and 6 (2.0%) in female. Two-hundred

TABLE 1. Visual acuity and OTS

OTS grade	n	%	Initial VA grade	n	%	Final VA grade	n	%
Grade 1 (0–44)	46	15.10	Grade 1	96	31.60	Grade 1	140	46.1
Grade 2 (45–65)	60	19.70	Grade 2	31	10.20	Grade 2	17	5.6
Grade 3 (66–80)	36	11.80	Grade 3	19	6.30	Grade 3	13	4.3
Grade 4 (81–90)	24	7.90	Grade 4	39	12.80	Grade 4	13	4.3
Grade 5 (91–100)	45	14.80	Grade 5	80	26.30	Grade 5	95	31.3
Adnexal	51	16.80	Unknown	39	12.80	Unknown	26	8.6
Neuro-ophthalmic	3	1.00						
Unknown	39	12.83						

Grade 1 was defined as 20/40 or better, grade 2 was 20/50 to 20/200, grade 3 was 19/200 to 1/200, grade 4 was hand motion or light perception, and grade 5 was no light perception.

OTS, Ocular Trauma Score; VA, visual acuity.

TABLE 2. Laterality, zone of injury, and associated injuries

Injury Type	Total number of injuries (%)
Unilateral, n (%)	131 (43.1)
Bilateral, n (%)	173 (56.9)
Globe/globe injury	97 (31.9)
Globe/adnexa	49 (16.1)
Adnexa/adnexa	22 (7.2)
Neuro/neuro	1 (0.3)
Globe/neuro	4 (1.3)
Closed globe, n (%)	
Zone 1	27 (8.9)
Zone 2	11 (3.6)
Zone 3	81 (26.6)
Open globe, n (%)	
Zone 1	19 (6.3)
Zone 2	11 (3.6)
Zone 3	84 (27.6)
Zone not applicable, n (%)	71 (23.4)
Oculoplastic, n (%)	
Adnexal injury	70 (23.0)
Retrobulbar hematoma	21 (6.9)
Eyelid injury	102 (33.6)
Enophthalmos	14 (4.6)
Lacrimal injury	12 (4.0)
Neuro-ophthalmic, n (%)	
Afferent pupillary defect	71 (23.4)
Direct optic nerve injury	50 (16.5)
Optic nerve avulsion	9 (3.0)
Diplopia	26 (8.6)
Cranial nerve injury	26 (8.6)
Anterior segment, n (%)	
Conjunctival chemosis	25 (8.2)
Corneal abrasion	14 (4.6)
Corneal laceration	30 (9.9)
Corneal foreign body	26 (8.6)
Corneoscleral laceration	25 (8.2)
Hyphema	55 (18.1)
Angle injury	22 (7.2)
Zonular dehiscence	40 (14.49)
Traumatic cataract	52 (17.1)
Retina and posterior segment, n (%)	
Globe rupture	19 (6.3)
Posterior rupture	18 (5.9)
Intraocular foreign body	38 (12.5)
Scleral laceration	47 (15.46)
Vitreous hemorrhage	109 (35.9)
Subretinal hemorrhage	61 (20.1)
Intraretinal hemorrhage	55 (18.1)
Macular hemorrhage	38 (12.5)
Traumatic retinal tear	59 (19.4)
Traumatic retinal detachment	49 (16.1)
Comotio retinae	49 (16.1)
Comotio retinae involving the macula	39 (12.8)
Chorioretinal rupture	34 (11.2)
Chorioretinal rupture involving the macula	19 (6.3)
Choroidal hemorrhage	48 (15.8)
Choroidal hemorrhage involving the macula	33 (10.9)
Choroidal rupture	11 (3.6)
Choroidal rupture involving the macula	9 (3.0)

Italicized represent those injuries or patterns of injury that occurred in greater than 25% of cases.

fifty-eight injuries (84.9%) occurred in Iraq and 46 (15.13%) happened in Afghanistan. The most common source of injury was improvised

explosive device in 183 eyes (60.2%), rocket-propelled grenade in 23 (7.6%), motor vehicle crash in 27 (8.9%), gunshot wound in 36 (11.8%), mines in 6 (2.0%), mortar in 10 (3.3%), helicopter crash in 3 (1.0%), other in 9 (3.0%), grenade in 6 (2.0%), and unknown in 1 (0.3%). Eye protection was not worn in 59 eyes (19.4%), worn in 59 (19.4%), and unknown or undocumented in 186 (61.2%).

Visual Acuity. Initial and final VA, and OTS category and raw scores are presented in Table 1. Change in VA was not able to be measured in 59 (19.4%) due to lacking initial or final VA and of these patients 22 (7.2%) were initially intubated. No change in final VA was found in 136 eyes (44.7%), although significantly more eyes showed improvement (92, 30.3%), than a decrease (17, 5.6%) in final VA ($p < 0.001$).

In univariate analysis, having an orbital fracture, a roof, medial, lateral, and floor fracture and an increasing number of walls fractured were all significantly associated with having a final VA less than 20/200 ($p < 0.001$) and having an orbital fracture, a roof, medial, lateral, and floor fracture with an OTS category of 1 or 2 ($p < 0.001$). In eyes with a fracture, repair of that fracture was not associated with either better visual outcome ($p = 0.13$) or an OTS category of 1 or 2 ($p = 1$). In a logistic regression analysis that included each fracture location as an independent predictor, roof ($p = 0.003$), medial ($p = 0.013$), and lateral fractures ($p = 0.023$) were significantly associated with final VA less than 20/200, while floor fractures were not ($p = 0.85$). Regression analysis found that the number of walls fractured ($p = 0.27$), a roof fracture ($p = 0.16$), orbital fracture ($p = 0.70$), and fracture repair ($p = 0.62$) were poor predictors for final VA less than 20/200 when associated injuries such as retinal detachment, phthisis, globe rupture or perforation, and optic nerve injury are included in the model (all $p < 0.001$).

Zone of Injury, Associated Injuries, Fracture Repair. Zone of injury, laterality, and associated ocular injuries are summarized in Table 2. A univariate analysis was completed on select associated injuries for comparison of patients with orbital fractures, by fracture subset roof, medial, lateral, and floor fractures and by increasing number of walls fractured (Table 3). Enophthalmos was associated with an increasing number of walls fractured ($p < 0.001$). Select systemic injuries were reviewed. Two-hundred sixteen (71.1%) had an associated facial injury. Neurologic injuries occurred in 121 (40.8%), traumatic brain injury in 157 (51.6%), skull fracture in 72 (23.7%), and neck injury in 14 (4.6%).

Orbital fractures were repaired in 14.8% ($n = 45$). Of these, five were repaired at Landstuhl Regional Medical Center and the rest were repaired at WRAMC. Due to concern for infection, orbital fracture repairs were not completed in theater at either a local hospital or a combat support hospital. Of the patients with repair at Landstuhl Regional Medical Center, it is difficult to evaluate if there was a difference in outcome by location of repair. One of these patients had an optic nerve avulsion and was no light perception, three of the patients had a final VA of 20/20 and 1 patient did not have an initial VA documented.

Analysis was completed to study the most common zone of injury by open versus closed injury (Table 4). There was a statistically significant trend towards a higher probability of open globe zone 3 injuries in patients with an orbital fracture ($p < 0.001$). In addition, a regression analysis was completed by zone and open versus closed injury to assess probability of final VA less than 20/200 (Table 5). More posterior zone and open rather than closed injury was statistically associated with final VA less than 20/200 (both $p < 0.001$).

DISCUSSION

Orbital fractures occur frequently in combat ocular trauma and are increasing in civilian trauma with a 50% rise in orbital fracture admissions from 2002 to 2008.²⁰ Previously reported rates of combat-related orbital fractures during the OIF and OEF collected by ophthalmologists, otolaryngologists, and maxillofacial surgeons have ranged from 12% to 35%.²⁻⁵ If approximately 15% of patients injured in combat have an ocular injury, as many as 5% of patients injured in combat could have an orbital fracture. In

TABLE 3. Univariate modeling of associated injuries

Fracture	Injury	OR (95% CI)	<i>p</i>	Fracture	Injury	OR (95% CI)	<i>p</i>
Orbital	TBI	2 (1.5–2.7)	<0.001	Lateral	TBI	1.9 (1.3–3.0)	0.002
Floor	TBI	1.5 (1.1–2.1)	0.006	Medial	TBI	2.6 (1.7–3.8)	<0.001
Roof	TBI	5.2 (2.9–9.6)	<0.001	Walls	TBI		<0.001
Orbital	Adnexa	4.2 (2.7–6.6)	<0.001	Lateral	Adnexa	2 (1.1–3.4)	0.01
Floor	Adnexa	3.9 (2.5–6.1)	<0.001	Medial	Adnexa	1.9 (1.1–3.2)	0.01
<i>Roof</i>	<i>Adnexa</i>	<i>1.1 (0.5–2.3)</i>	<i>0.7</i>	Walls	Adnexa		<0.001
Orbital	Diplopia	2.9 (1.5–5.6)	<0.001	Lateral	Diplopia	3.7 (1.8–7.6)	<0.001
Floor	Diplopia	2.4 (1.2–4.7)	0.006	<i>Medial</i>	<i>Diplopia</i>	<i>1.2 (0.5–2.8)</i>	<i>0.5</i>
Roof	Diplopia	2.6 (1.0–6.0)	0.02	Walls	Diplopia		<0.001
Orbital	RBH	2.9 (1.4–6.2)	0.002	Lateral	RBH	3.7 (1.6–8.0)	0.001
Floor	RBH	2.3 (1.1–4.8)	0.03	Medial	RBH	4 (1.8–8.4)	<0.001
Roof	RBH	3.5 (1.3–8.3)	0.006	Walls	RBH		<0.001
Orbital	APD	1.9 (1.3–2.7)	<0.001	Lateral	APD	2.8 (1.7–4.5)	<0.001
Floor	APD	1.7 (1.2–2.6)	0.005	Medial	APD	2.2 (1.4–3.4)	<0.001
Roof	APD	2.4 (1.3–4.2)	0.002	Walls	APD		<0.001
Orbital	ONI	4.2 (2.5–7.1)	<0.001	Lateral	ONI	6.1 (3.4–10.7)	<0.001
Floor	ONI	2.6 (1.5–4.3)	<0.001	Medial	ONI	4.1 (2.3–7.1)	<0.001
Roof	ONI	6.1 (3.2–11.3)	<0.001	Walls	ONI		<0.001
Orbital	RD	1.1 (0.7–1.6)	0.6	Lateral	RD	1.3 (0.7–2.3)	0.3
Floor	RD	1.3 (0.8–1.9)	0.3	<i>Medial</i>	<i>RD</i>	<i>1.7 (1–2.8)</i>	<i>0.02</i>
Roof	RD	1.3 (0.6–2.4)	0.5	Walls	RD		0.3
Orbital	VH	1.0 (0.73–1.4)	1	Lateral	VH	1.1 (0.7–1.7)	0.8
Floor	VH	1.1 (0.8–1.5)	0.6	Medial	VH	1.3 (0.9–2)	0.2
Roof	VH	2.3 (0.7–2.2)	0.4	Walls	VH		0.7
Orbital	Commotio	1.4 (0.9–2.1)	0.1	<i>Lateral</i>	<i>Commotio</i>	<i>1.7 (0.9–2.9)</i>	<i>0.06</i>
Floor	Commotio	1.4 (0.9–2.1)	0.2	Medial	Commotio	1.3 (0.7–2.2)	0.4
Roof	Commotio	1 (0.5–2.1)	0.9	Walls	Commotio		0.09
Orbital	CMAC	1.5 (0.9–2.4)	0.08	<i>Lateral</i>	<i>CMAC</i>	<i>1.9 (1–3.5)</i>	<i>0.03</i>
<i>Floor</i>	<i>CMAC</i>	<i>1.6 (1–2.7)</i>	<i>0.04</i>	Medial	CMAC	1.2 (0.6–2.1)	0.6
Roof	CMAC	0.9 (0.4–2.2)	1	<i>Walls</i>	<i>CMAC</i>		<i>0.05</i>
Orbital	Hyphema	1.0 (0.7–1.5)	1	Lateral	Hyphema	1.1 (0.6–1.9)	0.7
Floor	Hyphema	1.0 (0.6–1.5)	1	Medial	Hyphema	1.1 (0.7–1.9)	0.6
Roof	Hyphema	0.9 (0.4–1.8)	0.9	Walls	Hyphema		0.9
Orbital	CRrupture	1.5 (0.9–2.4)	0.1	<i>Lateral</i>	<i>CRrupture</i>	<i>2.3 (1.2–4.2)</i>	<i>0.008</i>
Floor	CRrupture	1.3 (0.8–2.3)	0.3	Medial	CRrupture	0.8 (0.4–1.6)	0.7
Roof	CRrupture	1.3 (0.5–2.9)	0.5	Walls	CRrupture		0.09
Orbital	ChoroidRupt	0.9 (0.4–1.8)	0.9	Lateral	ChoroidRupt	1.4 (0.4–3.7)	0.6
Floor	ChoroidRupt	0.8 (0.3–1.9)	0.7	Medial	ChoroidRupt	0.4 (0.04–1.4)	0.2
Roof	ChoroidRupt	1.1 (0.2–3.8)	0.7	Walls	ChoroidRupt		0.57

Orbital: Orbital fracture vs. those without. Floor, roof, lateral, and medial: Anatomic location of fracture. Walls: Increasing number of walls fractured.

APD, afferent pupillary defect; ChoroidRupt, choroidal rupture; CMAC, commotio maculae; CRrupture, chorioretinal rupture; ONI, optic nerve injury; OR, odds ratio; RBH, retinobulbar hematoma; RD, retinal detachment; TBI, traumatic brain injury; VH, vitreous hemorrhage.

Italicized fractures and particular injuries are those that are different in statistical significance than the other fracture types being analyzed.

the authors' current study, 34.2% of patients with ocular trauma had an orbital fracture; the higher rate is likely due to selection bias from collection from an ophthalmic database. Rates of orbital fractures in civilian trauma studies of maxillofacial trauma range from 22% to 36.3%.^{21–23} Orbital fractures in the WROTD resulted primarily from improvised explosive devices (60.2%) and gunshot wounds (11.8%), while in the civilian sector, common causes of injury are activities of daily living in the elderly, play accidents and sports in children, motor vehicle accidents and assault.^{21–23}

The WROTD offers a unique analysis of orbital fractures due its design by ophthalmologists with an emphasis on the collection of VA data. In univariate analysis, the authors' found that having an orbital fracture itself and an increasing number of walls fractured all lead to an increased risk of blindness as defined as VA less than 20/200 ($p < 0.001$). When roof ($p = 0.001$), medial ($p = 0.009$), lateral ($p = 0.016$), and floor ($p = 0.9$) fractures were compared all but floor fractures were found to be a significant risk of blindness. However, it is unlikely that orbital fractures themselves are resulting in blindness, but rather associated injuries. In

a multivariate analysis, neither number of walls fractured ($p = 0.1$) nor roof fracture ($p = 0.1$) were independent risk factors for final VA less than 20/200 when the associated injuries of retinal detachment, phthisis, globe rupture or perforation, and optic nerve injury were included in the model (all $p < 0.001$). However, approximately 40% of patients with an orbital fracture had a final VA less than 20/200 due to associated injuries. Considering an ocular trauma rate of nearly 15% with a third having an orbital fracture, approximately 2% of U.S. soldiers returning from OIF/OEF will be blinded in an injury associated with an orbital fracture. These rates of decreased vision associated with orbital fracture are significantly higher than the rates presented in civilian studies. In the authors' study, of those patients ($n = 17$) that had a change of final VA that decreased from initial VA, most had severe injuries: open globe injuries ($n = 7$), optic nerve injuries ($n = 6$), retinal detachment ($n = 6$), phthisis ($n = 6$), and underwent an enucleation ($n = 3$). It is difficult though to find a specific trend for cause of poor outcome in these patients.

Multiple studies^{6–10} have noted a general decline in vision associated with orbital fractures. One meta-analysis⁶ of 5 studies

Table 4. Analysis of open versus closed injury by zone

Injury Type	Probability	SE	95% CI
Closed zone 1	0.19	0.05	0.13–0.26
Closed zone 2	0.31	0.07	0.18–0.48
Closed zone 3	0.38	0.03	0.32–0.44
Open zone 1	0.25	0.05	0.16–0.35
Open zone 2	0.19	0.05	0.11–0.31
Open zone 3	0.44	0.04	0.37–0.51

SE, standard error.

TABLE 5. Probability analysis of final visual acuity less than 20/200 by zone and open versus closed injury

Injury Type	Probability	SE	95% CI
Zone 1	0.03	0.02	0.006–0.1
Zone 2	0.3	0.1	0.1–0.5
Zone 3	0.7	0.04	0.6–0.8
Closed	0.07	0.03	0.03–0.1
Open	0.6	0.09	0.4–0.7

SE, standard error.

found that 8.1% of orbital fractures had decreased VA and in orbital fractures other than pure blowout fractures, the frequency of decreased VA was higher than pure blowout fractures ($n = 532$; odds ratio, 2.23; 95% CI, 1.06–4.70). Other studies^{8,24} demonstrated visual loss varied from 0.32% to 10.8%, with an average incidence of 1.7% (88 total cases in 5,442 patients)⁸ in patients with facial fractures. In the authors' review of the literature, there is a paucity of reporting of VAs in papers describing orbital fractures. The most likely cause of the lack of discussion of VA is poor recording at the time of injury. An article²⁵ found that VA in the authors' emergency department was appropriately documented in only 16.5% of patients with a facial fracture before a focused teaching session with improvement to 57.1% afterward. However, even this rate is not clinically acceptable and demonstrates that this is an area that should be emphasized for ophthalmologists to educate the authors' colleagues to improve ophthalmic evaluation at the initial point of care. VA is critical to assess as a vision worse than approximately 20/30 has been shown to indicate an associated ocular injury ($p < 0.0001$).⁷

Associated ocular injury occurs commonly in orbital fractures. Incidence of concomitant ocular injury ranges from 9.8% to 31.8% in orbital fractures.^{8,24,26} In the authors' study, patients with orbital fractures were found to commonly have associated traumatic brain injury, retrobulbar hematoma, and optic nerve injury, but not retinal detachment, hyphema, vitreous hemorrhage, and choroidal rupture. In addition, the authors' patients had a significantly higher rate of open zone 3 injuries and more posterior zone, and open versus closed injuries were more commonly associated with a final VA less than 20/200. A study found that if patients with orbital fractures exhibit symptoms such as pain, blurry vision, diplopia, floaters or flashes, or photophobia they are more likely than asymptomatic patients to have a severe ocular injury such as hyphema, retinal tear, vitreous hemorrhage ($p < 0.009$).¹¹ In the same study, the average length of time to ophthalmology consult was 4 days, which could lead to serious complications in patients with a hyphema, retinal tear, or vitreous hemorrhage.

The authors' article had a reported rate of orbital fracture repair of 14.8%, which is lower than the reported rate in civilian

trauma of approximately 25%.²⁰ Length of time from evacuation from Iraq and Afghanistan to Washington, D.C. and/or complex polytrauma where the fracture repair was not a priority lead to an improved clinical picture by time of ophthalmic surgical evaluation at WRAMC. Also, many of these patients underwent complex retinal and corneal repairs and declined oculoplastic intervention. The indications and time to surgical repair is a controversial subject in oculoplastics.^{27,28} Debates in the literature stretch back to the 1950s with Smith and Regan²⁹ arguing for immediate exploration to prevent persistent diplopia and enophthalmos, and Putterman et al.³⁰ in the 1970s supporting a more conservative approach with many patients in their study improving without surgery at 6 months. However, a few recent studies possibly support a more conservative approach. Young et al.³¹ looked at CT scans of conservatively treated orbital blowout fractures and found that at 6 months postinjury, there was a reduction in herniation of orbital contents, joining of bony edges and smoothening of the orbital contour with 95% of eyes showing a decreased fracture volume. As many of the authors' patients were not repaired and showed clinical improvement by the time of arrival to WRAMC, it is possible that patients might show radiologic improvement earlier than presented in Young et al.³¹ Clinically, a recent study found that a patient who did not undergo surgical correction had statistically significant improvement of their vision by 1 week after injury ($p = 0.02$); and there was no difference in final VA at 6 months between those that were repaired and those that did not have surgery.³² Finally, operating on orbital fractures in patients with facial polytrauma, as many U.S. Servicemembers had suffered, has a higher risk for vision loss. A recent study³³ demonstrated an increased risk of severe vision loss from count fingers to no light perception in patients undergoing orbital floor repairs in the setting of multiple facial fractures (subgroup risk, 6.45%).

There were multiple limitations to this study. Primarily, early in the OIF and OEF, there was poor longitudinal patient data tracking from the point of injury to WRAMC due to lack of an effective electronic health record. Analysis of the data was complicated by incomplete records, difficulty in long-term tracking of soldiers once they left WRAMC, and impediments documenting initial VA making OTS and initial VA outcomes troublesome to assess.

In conclusion, orbital fractures are one of the most common ophthalmic injuries in combat ocular trauma. About 40% of patients in the authors' series remained legally blind (final VA <20/200) due to associated injuries such as optic nerve injuries, retinal detachment, globe injury, and the development of phthisis.

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Enucleations and Eviscerations for Combat Ocular Trauma Performed During Operations Iraqi and Enduring Freedom: 2001 to 2011

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Purpose: To describe the demographics and clinical outcomes of patients who underwent posttraumatic enucleation or evisceration during Operations Iraqi Freedom (OIF) and Enduring Freedom (OEF) from 2001 to 2011.

Methods: The Walter Reed Ocular Trauma Database is a retrospective case series of US Servicemembers and Department of Defense civilians who had combat ocular injuries in OIF and OEF. Data regarding posttraumatic enucleations and eviscerations performed during OIF and OEF were extracted. The main outcomes analyzed were the number of enucleations and eviscerations performed, location of the surgery, laterality, and graft type. The secondary outcome measures included: mechanism of injury and Ocular Trauma Score classification.

Results: One hundred nine enucleations and eviscerations were performed on the 890 eyes (12.24%). Sixty-three (57.80%) primary enucleations, 36 (33.03%) secondary enucleations, 5 (4.59%) postretinal detachment repair enucleations, and 5 (4.59%) primary eviscerations were completed. The surgeries were completed at a combat support hospital (57; 52.3%), or Walter Reed Army Medical Center (49; 45.0%). All surgeries were

unilateral except in 2 patients. The most common graft type used was silicone (n=56; 51.38%). Improvised explosive devices caused 76 (69.72%) eye injuries. Ocular Trauma Score were recorded as 56 (51.38%) between 0 and 44, 44 (40.37%) between 45 and 65, and unknown in 9 (8.26%).

Conclusion: Posttraumatic enucleation or evisceration due to devastating ocular trauma is required in about 15% of ophthalmic patients in modern combat trauma. The psychosocial impact on veterans who have required an enucleation or evisceration from combat trauma has been poorly studied and requires further review.

Key Words: Enucleation, evisceration, Operation Enduring Freedom, Operation Iraqi Freedom

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Ocular trauma was a common occurrence during Operation Iraqi Freedom (OIF; Iraq) and Operation Enduring Freedom (OEF; Afghanistan), as a reported 13% of US war casualties sustained an ocular injury.¹ Classically, the civilian ophthalmologists' most common indications for enucleation are a blind painful eye, malignancy, severe penetrating globe trauma, and phthisis, while evisceration is commonly performed for endophthalmitis or in patients with a bleeding disorder.² However, evisceration and enucleation are now commonly performed regardless of clinical situation at the preference of the surgeon.^{3,4} In combat ocular trauma, the indication for primary enucleation or evisceration is severe nonrepairable penetrating ocular injuries with expected poor final visual outcome and cosmetic results.^{5,6} The US Servicemembers (SMs) in the Walter Reed Ocular Trauma Database (WROTD) requiring enucleation and evisceration due to devastating ocular injury offer an interesting perspective on surgical management.

MATERIALS AND METHODS

During the conflicts of OIF and OEF from 2001 to 2011, injured US SM were air-evacuated from their respective theaters through Landstuhl Regional Medical Center (LRMC) in Germany to their final level of care at the former Walter Reed Army Medical Center (WRAMC). Data from these patients' injuries and timeline to care were collected in the WROTD. The data include elements collected on injured patients by ophthalmologists at 3 distinct levels of care: a combat support hospital (CSH) in Iraq or Afghanistan, LRMC, and ultimately, definitive care at WRAMC. Many patients injured during OIF and OEF were evacuated to WRAMC during this period; however, certain service members were evacuated to other large military domestic medical centers and their data were not collected in the WROTD. Data collection concluded in the

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postacute care phase when they entered the Veterans Affairs medical system, returned to their military unit, or permanently changed duty stations. The initial data elements included both inpatient and outpatient records transcribed to Microsoft Excel (Microsoft Corporation, Redmond, WA). Further description of the collection of the data in the WROTD is outlined in previous articles.^{1,7,8}

Patients who met inclusion criteria were any US SM or Department of Defense (DoD) civilians injured in OIF and OEF who underwent posttraumatic enucleation or evisceration. Excluded from the dataset were patients who had an injury outside of a combat zone, were neither US SM nor DoD civilians, or did not undergo enucleation or evisceration. The main outcomes analyzed were the number of enucleations and eviscerations performed, location where surgery was completed, laterality, and graft type. The secondary outcome measures included: additional surgical procedures, associated ocular injuries, mechanism of injury, and Ocular Trauma Score (OTS) classification.

The classification system used for trauma during initial collection was the Birmingham Eye Trauma Terminology.^{9,10} The patients' OTS were calculated as detailed by Kuhn et al.⁹⁻¹² Snellen visual acuities (VAs) were converted to vision grades for significant statistical analysis. The grades were defined as follows: Grade 1—VA of 20/40 or better, Grade 2—VA of 20/50 to 20/200, Grade 3—VA of 19/200 to 1/200, Grade 4—hand motion or light perception, and Grade 5—no light perception.

RESULTS

Demographics, Visual Acuity, and Ocular Trauma Score

During OIF and OEF, 104 enucleations and 5 eviscerations were performed on the 890 eyes in the WROTD (12.24%). Primary enucleations and eviscerations were primarily performed in Iraq or Afghanistan at a Role 3 CSH unless the patient was rapidly evacuated to Role 4 LRMC in Germany or Role 5 WRAMC in the United States, while secondary enucleations were all performed at WRAMC or LRMC (Table 1). Combat support hospital in theater has limited operating room space, but has the all of the necessary supplies to repair orbital injuries using plates and other materials, and has different materials for enucleation (Table 1). One patient required bilateral enucleations and another bilateral eviscerations. The mean time to enucleation or evisceration was 9.8 days after

TABLE 1. Enucleation Data

Location Performed	
Combat support hospital	57 (52.3%)
LRMC	3 (2.7%)
WRAMC	49 (45.0%)
Procedure	
Primary enucleations	63 (57.80%)
Secondary enucleations	36 (33.03%)
Postretinal detachment repair enucleations	5 (4.59%)
Primary eviscerations	5 (4.59%)
Implant	
Unknown	20 (18.35%)
Silicone	56 (51.38%)
MEDPOR (Stryker)	9 (8.26%)
Acrylic	7 (6.42%)
Dermis fat graft	2 (1.83%)

LRMC, Landstuhl Regional Medical Center; WRAMC, Walter Reed Army Medical Center.

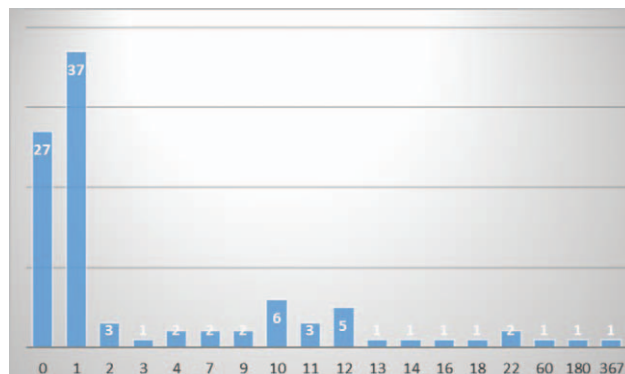


FIGURE 1. Time to enucleation in days.

injury (std 41.50, range 0–367) (Fig. 1). Time to enucleation was unknown in 12 (11.01%) eyes. Of the 109 surgical procedures, 57 (52.29%) were unilateral injuries, while 40 (36.70%) were bilateral globe-globe injuries, and 12 (11.01%) were bilateral globe-adnexal injuries. Geographically, 99 (90.83%) of injuries occurred in Iraq while only 10 (9.17%) occurred in Afghanistan. Further demographic data, description of eye protection use, and mechanism of injury are presented in Table 2. Example photographs of enucleated eyes that demonstrate the severity of the injury patterns are included (Fig. 2A-B).

Initial VAs were recorded as grade 5 in 96 (88.07%) injuries, grade 4 in 4 (3.67%) injuries, and unknown/undocumented in 9 (8.26%) injuries. Ocular Trauma Score were recorded as 9 (8.26%) unknown, 56 (51.38%) between 0 and 44, and 44 (40.37%) between 45 and 65.

Zone of Injury, Associated Injuries, and Surgeries

Zone of injury and associated neuro-ophthalmic, oculoplastic, and anterior and posterior segment injuries were analyzed (Table 3). Other nonophthalmologic injuries included facial injuries in 64 (58.72%) patients, neurologic injuries in 37 (33.94%) patients, traumatic brain injury in 42 (38.53%) patients, skull fractures in 15 (13.76%) patients, and neck injuries in 3 (2.75%) patients.

Additional surgeries were performed. Lid reconstruction was completed in 20 (18.35%) eyes and lacrimal surgery in 1 (0.92%) patient. Orbital wall fractures were repaired in 9 (8.26%) injuries. In the posterior segment, pars plana vitrectomies (4.59%) and pars plana lensectomies (4.59%) were completed in 5 eyes prior to enucleation.

TABLE 2. Demographics/Injury Data

Age, y	Mean 27.65 (range 19–53)
Gender	107 (98.17%) male/2 (1.83%) female
Eye protection	
Documented eye protection	36 (33.03%)
Documented without eye protection	18 (16.51%)
Undocumented	55 (50.46%)
Mechanism of injury	
Improvised explosive device	76 (69.72%)
Gunshot wound	13 (11.93%)
Rocket-propelled grenade	10 (9.17%)
Mortar	4 (3.67%)
Grenade	3 (2.75%)
Motor vehicle accident	1 (0.92%)
Mine	1 (0.92%)

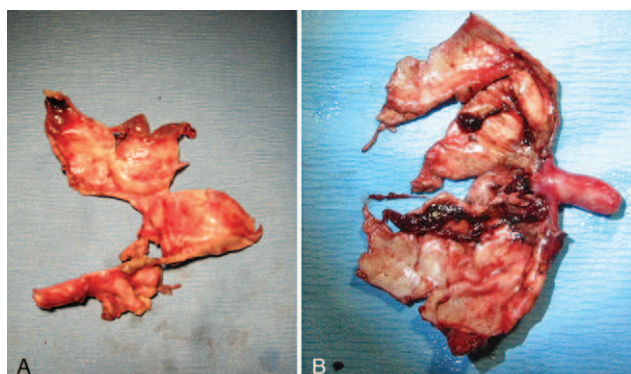


FIGURE 2. (A, B) Traumatic enucleations from combat injuries (Courtesy of Raymond Cho, MD).

DISCUSSION

Enucleations and eviscerations for severe penetrating open globe trauma occur commonly in combat ocular trauma.¹ Our reported rate of 12.24% of patients is close to the previously reported rate of 14.55% from Iraq in 2003 to 2005.⁵ As formerly discussed,^{3,6} the rate of ocular injury requiring enucleation has steadily declined from 50% in World War I, to 35% to 40% in World War II, to 27% in the Korean War, but has remained around 13% to 20% through the Vietnam War, Yom Kippur (1973) and Lebanon Wars (1982), Operation Desert Storm and to the present. Indications in combat trauma are significantly different from those in the civilian setting. Nonetheless, by reporting the retrospective data under the lens of modern surgical practice, the results can be relevant to the care of the warfighter as well as the care of patients in high-volume trauma centers.^{13,14} In addition, as domestic terrorists such as those in the Boston Marathon bombing begin to use improvised explosive devices, injuries of similar severity to Iraq and Afghanistan will need to be managed within the United States.¹⁵

In civilian practice, the most common indications for enucleation are retinoblastoma with reported rates from 35% to 58%.^{14,16} Trauma is the second most frequent indication of enucleation accounting for 24.1% of enucleations performed.¹⁴ However, the trauma in civilian practice is commonly due to slow-speed projectile, blunt injury, or a single foreign body fragment, while in combat injuries, enucleation is commonly performed because of severe high speed projected or explosive injuries. Both Thach et al⁵ and Mader et al⁶ discussed that their indications for primary enucleation in Iraq from 2003 to 2005 were to only remove eyes without possible cosmetic or visual potential. Attempts were made to repair any eye thought to have minimal visual potential. Finally, due to the concern for theoretical risk of sympathetic ophthalmia (SO) it was the protocol at WRAMC that all patients requiring an enucleation undergo surgery within 14 days of initial injury. There were 7 patients who exceeded the 2-week mark. The patients ≤ 60 days were all secondary enucleation with a final VA of no light perception prior to surgery. The 2 patients at 180 and 367 days were postretinal detachment repair and had developed phthisis. Early evacuation to WRAMC was performed as soon as possible so that the surgery could be completed within the 2-week timeframe.

The incidence of SO has been historically low with studies producing a retrospective incidence rate of around 0.14% to 0.5%.^{17–20} The treatment for SO remains controversial as some sources indicate a more conservative approach including progressive treatment with nonsteroidal anti-inflammatory drugs, corticosteroids, and finally immunosuppressive drugs.²¹ While another study suggests that many surgeons still recommend enucleation

TABLE 3. Zone of Injury and Associated Injury

Open Globe	
Zone 1	2 (1.83%)
Zone 2	4 (3.67%)
Zone 3	103 (94.50%)
Oculoplastic	89 (81.65%)
Retrobulbar hematoma	9 (8.26%)
Lid injury	65 (59.63%)
Enophthalmos	2 (1.83%)
Orbital fracture	62 (56.88%)
Orbital foreign body	25 (22.94%)
Lacrimal Injury	2 (1.83%)
Neuro-ophthalmic	29 (26.61%)
Afferent pupillary defect	34 (31.19%)
Direct optic nerve injury	16 (14.68%)
Optic nerve avulsion	5 (4.59%)
Cranial nerve injury	1 (0.92%)
Anterior segment	
Corneal laceration	11 (10.09%)
Corneal foreign body	4 (3.67%)
Corneo-scleral laceration	24 (22.02%)
Scleral laceration	44 (40.37%)
Hyphema	25 (22.94%)
Iris injury	37 (33.94%)
Iridodialysis	5 (4.59%)
Angle injury	25 (22.94%)
Zonular dehiscence	18 (16.51%)
Retina and posterior segment	
Globe rupture	12 (11.01%)
Intraocular foreign body	20 (18.35%)
Vitreous hemorrhage	56 (51.38%)
Vitreous avulsion	1 (0.92%)
Subretinal hemorrhage	21 (19.27%)
Intraretinal hemorrhage	16 (14.68%)
Macular hemorrhage	13 (11.93%)
Traumatic retinal tear	49 (44.95%)
Traumatic retinal detachment	50 (45.87%)
Macula-on retinal detachment	2 (1.83%)
Macula-off retinal detachment	45 (41.28%)
Traumatic macular hole	1 (0.92%)
Comotio retinae	5 (4.59%)
Chorioretinal rupture (sclopetaria retinitis)	4 (3.67%)
Chorioretinal rupture involving the macula	3 (2.75%)
Choroidal hemorrhage	48 (44.04%)
Choroidal hemorrhage involving the macula	33 (30.28%)
Choroidal rupture	3 (2.75%)
Choroidal rupture involving the macula	2 (1.83%)

within 2 weeks of traumatic injury to prevent SO from developing.¹⁸ In the context of OIF and OEF, the decision to enucleate due to the risk of SO was not well documented.^{5–6,8} Critically, in the WROTD there were no reported patients with SO. A single clinical report²² in 2006 created concern within the military ophthalmology community of a US SM injured in Iraq who underwent evisceration in theater; he subsequently developed SO and required treatment at an outside facility. This patient was found to have residual uveal tissue throughout his orbit due to the severe nature of the trauma endured and after appropriate treatment with steroids had a final VA of 20/20 off all medications after steroid taper.

Regarding evisceration, common civilian indications include leukocoria and endophthalmitis.² But, evisceration is becoming more frequently used in trauma injuries as the risk of sympathetic ophthalmoplegia is considered less concerning and the medical

management has improved.^{19,23} Evisceration also has the advantages of less disruption of the orbital anatomy, better prosthesis mobility, is technically simpler and has a lower rate of reoperation. For these reasons, evisceration has grown in popularity in the United States and the United Kingdom.^{3,4} Within the military community, there has been considerable debate about the use of evisceration versus enucleation due to the clinical report of SO after evisceration.²² The 5 reported primary eviscerations in this study were done in isolation by a few ophthalmologists who felt that the cosmetic outcome and mobility were better following evisceration and that the incidence of SO was sufficiently low to justify the use of evisceration instead of enucleation. Thach et al⁵ reported a higher rate of evisceration in 34 of 116 eyes (29.31%) in OIF from 2003 to 2005 versus 5 of 109 (4.58%) in our study. One of the coauthors, BWD, in his deployment to Afghanistan in 2014 to 2015 performed almost exclusively eviscerations. However, in certain patients with explosive globe rupture,^{5,6} the scleral tissue is split to pieces or there is no viable remaining ocular tissue making performance of an evisceration impossible. In addition, secondary eviscerations may have been performed at other DoD institutions and were not captured in the WROTD. Consideration of evisceration instead of enucleation in combat ocular trauma may be warranted particularly at combat-support hospitals where resources are limited.

Enucleation and evisceration have lifelong impacts on patients' mental, social, and physical well-being. A combined cosmetic defect and loss of VA for the warfighter can be debilitating for the patient and their loved ones. Using the VFQ-25, a recent review of US SMs with ophthalmic combat injuries found that those with a final VA of <20/200 had a lower visual quality of life in composite and all 11 subscales.²⁴ Unfortunately, there is a paucity of data on the effect of enucleation and evisceration in veterans and more research is needed to understand how the loss of vision and cosmetic factors effect veterans specifically. In civilian data, patients with enucleated eyes experience a greater prevalence of anxiety (11.8%) and depression (13.8%).²⁵ Patients should be assessed for phantom eye syndrome²⁶ or symptoms of pain, visual sensations, and sensation of seeing through the removed eye. Pain has been associated with increased anxiety and depression.²⁶ Critical to the military population, retinoblastoma survivors (most of whom required enucleation) compared with noncancer siblings were more likely to report posttraumatic stress symptoms of avoidance and hyperarousal ($P < 0.01$).²⁷

While the WROTD provides a unique dataset for combat ocular trauma, subjects frequently had incomplete records and poor documentation of follow-up. Many of the data elements such as initial VA were often not obtained due to the severe trauma and intubated state of the patient population. In addition, the enucleation cohort generally had less follow-up than other patients as after their surgery they were deemed clinically stable. Many patients were sent to the ocularist for prosthetic fitting at 6 weeks and then either transitioned back to their home unit, entered the Veterans Affairs medical system, or left the military.

In conclusion, modern combat enucleations or eviscerations are completed on about 13% to 20% of patients with combat ocular trauma or approximately 2% of all patients injured in OIF and OEF. In addition, although civilian data have reviewed the psychosocial effect of enucleation and evisceration, further data should be collected in the US Veteran's Affairs hospital system or international veteran hospital systems on the psychosocial effect upon veterans who underwent enucleation and evisceration.

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Neuro-Ophthalmic Injuries With Systemic Neurologic Injury or Traumatic Brain Injury in Operation Iraqi Freedom and Operation Enduring Freedom

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Background: To analyze the final visual acuity (VA) of neuro-ophthalmologic injuries (NOI) in combat ocular trauma and to study the association of NOI with systemic neurologic injury (SNI) and traumatic brain injury (TBI).

Methods: The Walter Reed Ocular Trauma Database was reviewed. Inclusion criteria were any US service member and Department of Defense civilians who suffered NOI, SNI, or TBI in Operation Iraqi Freedom or Operation Enduring Freedom. The primary outcome measure was the rate of

poor final VA in patients with an NOI with secondary outcome measures the rate of SNI and TBI in patients with NOI.

Results: One hundred seventy-eight (20.00%) of 890 eyes had an NOI. Optic nerve injury was observed in 79 (44.38%) eyes, other cranial nerve injury in 68 (38.20%), Horner syndrome in 4 (2.25%), diplopia in 45 (25.28%), and ptosis in 13 (7.30%). In patients with NOI, 76 (42.69%) eyes had a final VA less than 20/200. In injured eyes ($n = 359$) of patients ($n = 251$) with TBI, 154 eyes (34.26%) had a final VA less than 20/200. In multivariate analysis, optic nerve injury ($P < 0.001$), unlike TBI ($P = 0.47$), was associated with final VA less than 20/200. SNI ($n = 229$) had a statistically significant association (odds ratio 29.8, 95% confidence interval 19.2–47.8, $P < 0.001$) with NOI. Optic nerve injury and cranial nerve injury were associated with TBI and SNI (all, $P < 0.001$).

Conclusion: Optic nerve injury and cranial nerve injury are associated with TBI and SNI. Optic nerve injury, but not TBI or cranial nerve injury, is associated with a poor final VA.

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With the increased prevalence of improvised explosive device (IED) blast trauma and survival of combat injury in modern warfare, severe ocular injuries have increased (1–6). Previous studies have found that in populations of ocular injuries, approximately 5%–66% occur with neurologic injuries (3,7–17). These neurologic injuries frequently include neuro-ophthalmic injuries (NOI) and traumatic brain injury (TBI). The incidence of concomitant TBI and ocular injury has been investigated (3,18–21); however, these studies encompass populations that are difficult to compare due to their exclusion criteria. Few studies have covered rates of specific NOI and concomitant systemic neurologic injury (SNI).

The objectives of this study were 3-fold: report on the incidence of NOI and associated SNI and TBI in combat

ocular trauma; analyze various NOI and their association with SNI and TBI; and assess the rate of poor final visual acuity (VA) less than 20/200 in NOI and complete a multivariate analysis to study whether NOI and TBI were risk factors for poor final visual outcome.

METHODS

This study was a retrospective compilation of data from US service members or Department of Defense (DoD) civilians injured in Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF). Patients were evacuated between 2001 and 2011 from the respective theater of operations in Iraq or Afghanistan most often to Landstuhl Regional Medical Center (LRMC), Germany, and then on to the former Walter Reed Army Medical Center (WRAMC) in Washington, DC. Institutional Review Board approval was obtained from WRAMC, which developed the Walter Reed Ocular Trauma Database (WROTD). Further description of the data collection is outlined in previous studies (3,9). Data were collected on Microsoft Excel (Microsoft Corporation, Redmond, WA), housed on SPSS (IBM, New York), and then transferred to statistical software (STATA 14.0, College Station, TX) for data analysis.

Inclusion criteria were patients who were either US service members or DoD civilians injured in OIF and/or OEF recorded in the WROTD who had an NOI as defined as an optic nerve injury, optic nerve avulsion, ptosis, diplopia, cranial nerve injury, and/or Horner syndrome. All NOI injuries, symptoms (diplopia), and diagnoses (optic nerve injury, other cranial nerve injury, Horner syndrome, and ptosis) were defined based off of review of patient records and what was diagnosed by the managing ophthalmologists. In addition, a separate database review was completed for patients with a TBI to assess both its association with NOI and effect on final VA. Exclusion criteria were injuries sustained outside of a combat-related injury or non-DoD civilian trauma. The primary outcome measure was the rate of poor final VA in patients with an NOI with secondary outcome measures being the rate of associated SNI and TBI.

Using the Birmingham Eye Trauma Terminology (BETT) and converting Snellen acuities to vision grades, injuries were classified and analyzed (22). Grade 1 was equivalent to 20/40 or better, Grade 2 was 20/50 to 20/200, Grade 3 was 19/200 to 1/200, Grade 4 was hand motion or light perception, and Grade 5 was no light perception. The patients' ocular trauma scores (OTS) were calculated as described by Kuhn et al (23). When a patient was first conscious, providers assessed initial VA; however, because some of these wartime injuries were urgent and/or severe cases, VA often could not be tested until after initial surgeries and many times not until after they had arrived at WRAMC. For the entire data set ($n = 890$), 57 patients were intubated, and 44 eyes were missing data for initial

VA. Per protocol, providers tested VA in the immediate postinjury period (as possible), 20–50 days after injury, 150–200 days after injury, and finally at the last documented VA date. Realistically, in many cases, only initial and final VAs were obtained. Because of the limitations of documentation, intermediate VAs were not analyzed, but the eyes without intermediate VAs were not excluded from the data set.

Statistical Analysis

Univariate analysis was completed using the Fisher exact test for categorical variables and the Wilcoxon rank-sum test with continuity correction for continuous variables. Odds ratios (ORs) and 95% confidence intervals (CIs) given for categorical variables were also computed through the Fisher method. Multivariate analysis was completed using binomial logistic regression; significance was assessed using the Type 3 likelihood ratio test as implemented in the “car” package (24). Univariate and multivariate analyses discarded cases with missing information and analyzed records in which none of the variables tested in that analysis had missing values; proportions and incidence rates counted the total number of positive incidences over the total number of eyes in the set. Alpha was set at 0.05 for all analyses.

RESULTS

Neuro-ophthalmic Injuries

A total of 178 (20.00%) of 890 eyes in the WROTD had an NOI as described in Table 1. Patient demographic information, mechanism of injury, and eye protection use were compiled (Table 1). A list of previously reported rates of NOI was completed (See **Supplemental Digital Content**, Table E1, <http://links.lww.com/WNO/A386>) (3,8,10,17,19,21,25–37). Initial and final VA scores and OTS were recorded in Table 2.

Systemic Neurology Injuries

Analyses were completed to review associated systemic neurologic injuries to NOI as demonstrated by Table 3. Of all subjects in the WROTD with SNI ($n = 229$), there was a statistically significant relationship (OR 29.8, 95% CI 19.2–47.8, $P < 0.001$) with neuro-ophthalmic injury.

Traumatic Brain Injury

A separate subanalysis of all subjects in the WROTD with a TBI ($n = 251$ patients, 359 eye injuries) was completed: 79 eyes were noted with an afferent pupillary defect, 47 eyes had a reported optic nerve injury, 17 patients experienced diplopia, 3 eyes were associated with a Horner syndrome, and 45 eyes were associated with a cranial nerve injury. Associations between specific NOI injuries and TBI were studied (Table 3). In addition, a separate analysis of the initial and final VA and OTS for patients with TBI injuries is presented in Table 4.

TABLE 1. Neuro-ophthalmic injury incidence by type (n = 178)

Neuro-ophthalmic Injuries and Signs	Incidence
Afferent pupillary defect	76 (42.70%)
Diplopia	45 (25.28%)
Other cranial nerve injury	68 (38.20%)
Horner syndrome	4 (2.25%)
Optic nerve avulsion	13 (7.30%)
Optic nerve injury	79 (44.38%)
Ptosis	13 (7.30%)
Demographics	
Unilateral injuries	94 (52.81%)
Bilateral injuries	84 (47.19%)
Average age (yrs)	27.8 (range 19–48)
Injured in Iraq	159 (89.33%)
Injured in Afghanistan	19 (10.67%)
Mechanism	
Improvised explosive device	93 (52.25%)
Gunshot wound	27 (15.17%)
Motor vehicle accident	19 (10.27%)
Rocket propelled grenade	18 (10.11%)
Other	9 (5.06%)
Mine	4 (2.25%)
Mortar	4 (2.25%)
Helicopter crash	2 (1.12%)
Eye protection	
Adherent	48 (26.97%)
Nonadherent	34 (19.10%)
Undocumented	96 (53.93%)

Risk of Poor Visual Acuity

A multivariate analysis was completed to compare risk factors for poor final VA less than 20/200. For this analysis, retinal detachment, globe rupture, and perforating injury were included as they are components of the OTS. Optic nerve injury was selected instead of a relative afferent pupillary defect (fourth component of the OTS), as at times the afferent pupillary defect that was recorded in the WROTD may have been completed by a nonophthalmologist. Endophthalmitis, the last component of the OTS, was not included as it was very rare in the WROTD. Phthisis was selected because it was a common cause of blindness in this cohort. Cranial nerve injury was selected because of its common association with TBI and SNI. Finally, TBI and SNI were included. Optic nerve injury, retinal detachment, phthisis, globe rupture, and penetrating injury were all significant risk factors (all $P < 0.001$) for final VA less than 20/200. Cranial nerve injury ($P = 0.6$) and TBI ($P = 0.47$) were equivocal, and SNI was noted to have a negative correlation with poor visual outcome ($P = 0.007$).

DISCUSSION

Neuro-ophthalmic trauma occurs commonly in combat injuries because of a variety of mechanisms of injury and along various components of the visual pathway. Blast

injuries from IEDs have led to a higher rate of TBI and NOI than in civilian trauma. Animal studies have demonstrated blast injuries cause NOI along the entire visual pathway, not isolated to a particular region (38–41). At the cellular level, blast injuries cause hypertrophy of astrocytes, physical destruction of the neuron cytoskeleton, ionic imbalances, and ultimately cell death (42). Our analysis demonstrated an NOI rate of 20.00% in 890 combat injured eyes. Previous rates of NOI in ocular trauma have a wide range (5%–66%) with wartime trauma generally having a higher rate (3,7–17). Combat injuries place patients at increased risk of multisystem trauma and high-energy injuries. NOI may be more prevalent in these injury patterns because of the less localized injury. However, in our study of patients injured in combat, we found the rate of NOI in ocular trauma closer to the distribution of civilian than previously reported combat rates.

There is a wealth of literature in civilian ocular trauma that discusses the rates of specific NOI in ocular injuries. Optic nerve injury represents approximately 20% of all ocular trauma (3,7), while cranial nerve injury among all ocular trauma has been noted at 6% (3). However, it can be difficult to compare civilian studies with our study as they often focus on different sets of NOI signs or represent highly specified subsections of the population. In addition, the mechanism of injury often involves a higher velocity object in military trauma with the introduction and use of IEDs. One study (26) noted 2% of civilian ocular traumas were open globe injuries, 0.5% were optic nerve injuries, and the most common cause of ocular injury was superficial foreign bodies (33%). In the WROTD, 37.98% of eyes had open globe injuries, 8.88% had optic nerve injuries, and 33.03% of total eyes had orbital fractures. These data suggest that the rates of optic nerve injuries and open globe injuries were more prevalent in OIF and OEF in ocular traumas, compared with civilian settings, and this can likely be attributed to high velocity mechanism of injury in IED blasts in the combat environment.

Differentiating between diffuse TBI-dependent visual impairment and a specific NOI pathway injury visual impairment can be difficult. A study of civilian trauma demonstrated 11% of TBI patient suffered a concurrent Zone 3 injury or approximately 5 mm posterior to the limbus (43). A study by Brahm et al (44) found that combat injured inpatients and outpatients with TBI had VA loss of 20/200 or less of 13% and 1.6%, respectively. Previous research indicates 39%–66% of wartime patients with mild-severe TBI have some form of ocular injury (9,45). Civilian trauma studies similarly revealed 30%–40% TBI patients suffer an ocular injury (46,47). More specifically, the rates of optic nerve injuries in patients with TBI have been reported at rates of 0.1%–22% (18,48,49). In our study, we found that approximately 35% of patients with a TBI had a final VA less than 20/200. Although optic nerve injuries ($P < 0.001$) have been found to be a risk

TABLE 2. Ocular trauma score (OTS) and VA in neuro-ophthalmic injuries (n = 178)

OTS Category (Raw Score)		No. of Eyes, %	
5 (91–100)		16 (8.99)	
4 (81–90)		9 (5.06)	
3 (66–80)		23 (12.92)	
2 (45–65)		40 (22.47)	
1 (0–44)		23 (12.92)	
Adnexal		17 (9.55)	
Neurologic		34 (19.10)	
Unknown		16 (8.99)	
Initial VA Grade	No. of Eyes, %	Final VA Grade	No. of Eyes, %
Grade 1 ($\geq 20/40$)	62 (34.84)	Grade 1 ($\geq 20/40$)	73 (41.10)
Grade 2 (20/200–20/50)	18 (10.11)	Grade 2 (20/200–20/50)	12 (6.74)
Grade 3 (1/200–19/200)	12 (6.74)	Grade 3 (1/200–19/200)	12 (6.74)
Grade 4 (LP/HM)	31 (17.42)	Grade 4 (LP/HM)	19 (10.67)
Grade 5 (NLP)	39 (21.91)	Grade 5 (NLP)	45 (25.28)
Unknown	16 (8.99)	Unknown	17 (9.55)
Change in Visual Acuity		No. of Eyes, %	
Improved		53 (34.54)	
Worsened		14 (4.74)	
No change		84 (40.67)	
Unknown		18 (11.14)	
Initially intubated		9 (8.91)	

HM, hand motion; LP, light perception; NLP, no light perception; VA, visual acuity.

factor for final VA less than 20/200, in our study, TBI itself was not ($P = 0.47$). However, TBI was more likely to occur with OTS Category 1 or 2 injuries (OR 1.55, 95% CI 1.1–2.18, $P = 0.01$).

From our review of the literature, there is a paucity of analyses studying the relationship of systemic neurologic injuries and NOI. We found that patients who had systemic neurologic injuries had a very strong relationship (OR 29.8, 95% CI 19.2–47.8, $P < 0.001$) with NOI. Direct optic nerve injuries and cranial nerve injuries ($P < 0.001$) but not diplopia, ptosis, Horner, or optic nerve avulsion were associated with an SNI. However, the latter injuries had very low observed rates in our study, and this may contribute to their lack of significance. In addition, although counterintuitive, a negative correlation was found between SNI and

poor visual outcome ($P = 0.007$) in the multivariate model. This is likely due to the strength of association between the other variables in this model and poor visual outcome. Further research into this observation is required. These data demonstrate the importance of having patients with an NOI be evaluated by the neurology service for associated systemic neurologic injuries.

There were multiple limitations to this study. Wartime injuries are urgent, and in severe cases, the initial VA could not be tested until after surgery or late in the patient's care. This made calculating OCT and predicted VA outcomes troublesome for certain patients. In addition, relatively poor longitudinal patient data tracking from the point of injury to WRAMC, where some patients were rapidly transferred from WRAMC to other hospitals, made long-term

TABLE 3. Systemic neurologic injury and traumatic brain injury and associated specific neuro-ophthalmic injury

Systemic Neurologic Injury				TBI			
Injury	OR	95% CI	P	Injury	OR	95% CI	P
Optic nerve injury	3.42	2.08–5.65	<0.001	Optic nerve injury	2.4	1.45–3.98	<0.001
Optic nerve avulsion	1.56	0.40–5.46	0.54	Optic nerve avulsion	1.3	0.35–4.48	0.78
Ptosis	0.99	0.22–3.58	1	Ptosis	1.02	0.28–3.58	1
Cranial nerve injury	4.05	2.38–7.00	<0.001	Cranial nerve injury	2.98	1.74–5.22	<0.001
Horner	0.56	0.01–5.72	0.7	Horner	1.78	0.2–21.5	0.66

CI, confidence interval; OR, odds ratio; TBI, traumatic brain injury.

TABLE 4. Ocular trauma score (OTS) and visual acuity in traumatic brain injury (n = 359 eyes)

OTS Category (Raw Score)		No. of Eyes, %	
5 (91–100)		56 (15.60)	
4 (81–90)		28 (7.80)	
3 (66–80)		56 (15.60)	
2 (45–65)		59 (16.43)	
1 (0–44)		43 (11.98)	
Adnexal		27 (7.52)	
Neurologic		34 (9.47)	
Unknown		56 (15.60)	

Initial VA Grade	No. of Eyes, %	Final VA Grade	No. of Eyes, %
Grade 1 ($\geq 20/40$)	111 (30.92)	Grade 1 ($\geq 20/40$)	182 (50.70)
Grade 2 (20/200–20/50)	38 (10.58)	Grade 2 (20/200–20/50)	26 (7.24)
Grade 3 (1/200–19/200)	27 (7.52)	Grade 3 (1/200–19/200)	15 (4.18)
Grade 4 (LP/HM)	59 (16.43)	Grade 4 (LP/HM)	27 (7.52)
Grade 5 (NLP)	68 (18.94)	Grade 5 (NLP)	81 (22.56)
Unknown	56 (15.60)	Unknown	28 (7.8)

HM, hand motion; LP, light perception; NLP, no light perception; VA, visual acuity.

outcomes difficult to assess. Patients with neuro-ophthalmic injuries unrecognized at the point of injury, minimal enough to not be evacuated from theater, or severe enough that they resulted in death before arriving to Walter Reed Army Medical Center were not captured in this study. Finally, systemic neurologic injuries, TBI, ptosis, and diplopia were loosely defined in our study, and further specific analysis examining peripheral vs central neurologic injuries is needed.

In conclusion, this article raises interesting associations between NOI and SNI and TBI. NOI occurs commonly in combat eye injuries (20%) and is very strongly associated with SNI and TBI. Cranial nerve injuries and optic nerve injuries are associated with SNI and TBI (all, $P < 0.001$). Direct optic nerve injury, but not TBI or cranial nerve injury, was a risk factor for a poor final VA less than 20/200. Future wartime ophthalmic databases should include better characterization of NOI and its correlation with TBI and SNI. In addition, we encourage further analysis in civilian trauma data to evaluate for the correlation between these injuries and to have a better understanding of final visual outcome in these patients. Finally, better research collaboration particularly for evaluation of the correlation between NOI and systemic neurologic evaluation between neurology and ophthalmology services is critical.

STATEMENT OF AUTHORSHIP

Category 1: a. Conception and design: all authors; b. Acquisition of data: all authors; c. Analysis and interpretation of data: all authors. Category 2: a. Drafting the manuscript: all authors; b. revising it for intellectual content: all authors. Category 3: a. Final approval of the completed manuscript: all authors.

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Self-Reported Visual Quality of Life After Combat Ocular Trauma

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ABSTRACT Objectives: To describe the visual outlook and quality of life of service members after combat ocular trauma. Methods: In a single-center, prospective observational study of service members sustaining ocular trauma, participants underwent a series of ocular examinations and noninvasive tests, including the National Eye Institute Visual Functioning Questionnaire (VFQ-25). Results: Of the 165 enrolled participants, 137 completed the VFQ-25. The mean VFQ-25 composite score was 74.4 ± 20.7 (range: 1.4–100). Among 118 participants with visual acuity assessment, 92% had best corrected visual acuity (BCVA) of 20/20 or better in at least one eye. Among participants with severe vision loss (BCVA $\leq 20/200$), there was no statistically significant difference in self-reported general health compared to those without severe vision loss ($p = 0.17$). However, there was a significantly lower visual quality of life reported in the composite score and all of the 11 subscales of the VFQ-25. Conclusions: While this study provides evidence that combat ocular trauma is associated with a lower visual quality of life, limitations include the relatively small sample size and the limited documentation of the use of eye protection at time of injury among participants.

INTRODUCTION

Trauma is one of the leading causes of unilateral vision loss worldwide, resulting in an estimated 18 million people with unilateral blindness or low vision. Over 1 million people worldwide have lost vision in both eyes because of trauma.^{1,2} Although the eyes occupy only 0.1 percent of the total body surface,³ ocular trauma accounts for three percent of emergency department visits in the United States.^{3,4}

Among military service members injured during combat before the 20th century, eye injury rates were less than four times the expected percentage based on body surface area. This rate has steadily increased during the past century to a rate over 50 times the expected percentage during recent conflicts.³ During the first 5 years of Operation Iraqi Freedom and Operation Enduring Freedom, 13% of combat casualties requiring evacuation sustained significant ocular injury.⁵ Improvements in both body armor and medical care to combat casualties have likely resulted in injured personnel

who once would have died of thoracic and abdominal injuries who now present with nonfatal ocular injuries.³

Although numerous published reports have examined the quality of life of combat casualties, much of the focus of these studies has been on the evaluation of the effect of traumatic brain injury on quality of life.^{6–12} To our knowledge, no studies have investigated the visual quality of life of service members following combat ocular trauma. In this study, we describe the subjective visual outlook and visual quality of life of service members after combat ocular trauma. Understanding the impact of combat ocular trauma on visual quality of life will guide improvements in medical and surgical treatment, assist in the advancement of eye protection, and help the development of improved visual rehabilitation services and counseling.

METHODS

This is a single-center, prospective observational study of consecutive service members sustaining ocular trauma during Operation Iraqi Freedom and Operation Enduring Freedom who were evacuated to Walter Reed Army Medical Center or subsequently Walter Reed National Military Medical Center between December 6, 2006, and February 13, 2013. Approval was obtained from the Walter Reed Army Medical Center and the Walter Reed National Military Medical Center Institutional Review Boards before study implementation. All participants or their legally authorized representative gave written informed consent. Participants were included if they were at least 18 years old and had a history of a combat injury to head, face, or neck with ocular injury. Participants were excluded if they were unwilling or unable to undergo vision testing and/or special sensory or diagnostic testing, due to mental or physical conditions. When feasible, participants received a comprehensive baseline ocular examination and a standard battery of noninvasive

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TABLE I. Description of Injuries and Study Population

Characteristic	<i>n</i> (%)
Age (Years)	
<20	5 (3.9)
20–29	89 (69.5)
30–39	23 (18.0)
40–49	10 (7.8)
50–59	1 (0.8)
Mean (SD)	26.8 (7.0)
Documented Use of Eye Protection at Time of Injury	
Yes	48 (35.0)
No	18 (13.1)
Not Documented	71 (51.8)
Eye Injured	
Right Eye Only	57 (41.6)
Left Eye Only	55 (40.1)
Bilateral	25 (18.2)
Location of Injury	
Iraq	87 (63.5)
Afghanistan	40 (29.2)
Not Documented	10 (7.3)
Mechanism of Injury	
Blast	87 (63.5)
Gunshot	6 (4.4)
Other (Motor Vehicle Accidents, Blunt, Falls, etc.)	10 (7.3)
Not Documented	34 (24.8)
BCVA at Time of VFQ-25	
Better Eye	
20/10–20/15	60 (43.8)
20/20	45 (32.8)
20/25–20/40	6 (4.4)
20/50–20/150	3 (2.2)
20/200 or Worse	4 (2.9)
Worse Eye	
20/15	17 (12.4)
20/20	26 (19.0)
20/25–20/40	21 (15.3)
20/50–20/150	12 (8.8)
20/200 or Worse	42 (30.7)
Not Documented	19 (13.9)

tests, including the National Eye Institute Visual Functioning Questionnaire (VFQ-25).^{13,14} Participants were excluded from data analysis if they failed to complete the VFQ-25.

The VFQ-25 is a 25-item questionnaire that was developed to assess the effect of eye disorders on a patient's visual quality of life. It includes 24 items grouped into 11 subscales and a general health item. The questionnaire was self-administered by participants and scored on a scale of 0 to 100 in accordance with the VFQ-25 scoring algorithm, with a score of 100 indicating the best visual quality of life. Normative data have previously been described for cohorts with chronic eye disease and individuals free of known eye disease.^{13–23}

Injury and clinical data were captured from records or by self-report at the time of enrollment and included: demographics, theater of injury, duration of follow-up, mechanism of injury, documented use of eye protection, best corrected visual acuity (BCVA), and slit-lamp exam. Due to the smaller sample size, the VFQ-25 composite score is presented and compared. Subscale scores are presented descriptively to present functional ability in this population. Statistical analysis was performed with a *p* value of 0.05 considered statistically significant. A Student's *t* test was used to test hypotheses regarding VFQ-25 composite score, sex, age, injury cause, injury location, and number of eyes injured.

RESULTS

Of the 165 enrolled participants, 137 completed a VFQ-25 (83% of total enrolled). Descriptions of the injuries of the study population are described in Table I. The mean age was 26.8 years, with more than half of the participants between 20 and 29 years (range: 18–51 years). The majority of participants were male (*n* = 134; 98%). Among the 118 participants who completed a visual acuity assessment, 105 (92%) had BCVA of 20/20 or better in at least one eye. There were nine (8%) participants with mild or moderate vision loss (BCVA <20/20 and >20/200), and four (3%)

TABLE II. VFQ-25 Composite and Subscale Data for All Participants and Stratified by BCVA in Better Eye

VFQ-25 Subscales	Overall (<i>n</i> = 137)	BCVA ≤20/200 (<i>n</i> = 4)	BCVA >20/200 (<i>n</i> = 114)	<i>p</i> Value
	Mean ± SD	Mean ± SD	Mean ± SD	
General Health	65.8 ± 22.1	81.3 ± 12.5	65.5 ± 22.7	0.17
General Vision	64.1 ± 22.3	15.0 ± 10.0	67.1 ± 20.4	<0.001
Ocular Pain	74.0 ± 20.3	53.1 ± 18.8	74.5 ± 19.2	0.03
Near Activities	72.7 ± 26.6	18.8 ± 17.2	74.3 ± 24.7	<0.001
Distance Activities	75.6 ± 24.0	31.3 ± 12.5	76.7 ± 22.4	<0.001
Social Function	84.2 ± 22.8	31.3 ± 16.1	86.1 ± 19.9	<0.001
Mental Health	71.2 ± 26.0	29.7 ± 21.9	72.6 ± 24.5	0.001
Role Difficulties	72.8 ± 28.6	25.0 ± 35.4	73.9 ± 27.0	0.001
Dependency	81.4 ± 26.9	31.3 ± 37.5	83.2 ± 24.6	<0.001
Driving	74.3 ± 27.1	0.0 ± 0.0	73.1 ± 26.4	<0.001
Color Vision	91.4 ± 20.7	25.0 ± 35.4	93.3 ± 16.1	<0.001
Peripheral Vision	61.0 ± 29.5	25.0 ± 28.9	61.3 ± 27.9	0.01
Composite	74.4 ± 20.7	27.5 ± 11.1	75.8 ± 18.3	<0.001

TABLE III. Mean Composite Scores of the VFQ-25 by Injury Characteristics.

Characteristic	Mean $\pm$ SD
Location of Injury	
Iraq	73.9 $\pm$ 20.1
Afghanistan	71.5 $\pm$ 23.9
<i>p</i> Value	0.604
Documented Use of Eye Protection at Time of Injury	
Yes	80.0 $\pm$ 22.5
No	72.6 $\pm$ 22.2
<i>p</i> Value	0.294
Eye Injured	
Unilateral Injury	76.4 $\pm$ 19.1
Bilateral Injury	66.2 $\pm$ 21.2
<i>p</i> Value	0.139

participants with severe vision loss (BCVA $\leq$ 20/200) in the better eye.

VFQ-25 subscale data are presented in Table II. The mean overall composite score was 74.4 (SD = 20.7; range: 1.4–100). The mean number of days between injury and VFQ-25 completion was 339 days (SD = 537; range: 3–2,753). Among participants with severe vision loss (BCVA $\leq$ 20/200), there was no statistically significant difference in self-reported general health compared to those without severe vision loss ($p = 0.17$). However, there was a statistically significant lower visual quality of life reported in the composite and all of the 11 subscales of the VFQ-25 (Table II). Table III shows the VFQ-25 composite scores by injury characteristic. There were no statistically significant differences in VFQ-25 composite scores when comparing: location of injury ($p = 0.61$), use of eye protection ($p = 0.29$), or unilateral vs bilateral injury ($p = 0.14$).

Among participants with documented use of eye protection at the time of injury, there was a trend for higher visual quality of life reported in the composite and all of the subscales of the VFQ-25 except color vision. However,

this trend was not statistically significant for the composite or any of the subscales (Table IV).

DISCUSSION

This study is the first to use the VFQ-25 to describe the visual quality of life of service members following combat ocular trauma. Previous studies have characterized the visual quality of life of individuals with eye disease and free of known eye disease.^{13–23} A 4- to 6-point change in VFQ-25 score has previously been shown to represent a clinically meaningful change corresponding to a 15-letter change in BCVA.²⁴ The VFQ-25 composite score for service members following combat ocular trauma is lower than the original reference cohort of 122 individuals free of known eye disease (74 $\pm$ 21 in our cohort compared to 92 $\pm$ 21 as reported by Noble et al.).²⁵ The VFQ-25 composite score is also lower in this study population than that among patients previously reported with glaucoma (mean VFQ-25 composite score 88 $\pm$ 12),¹⁵ age-related macular degeneration (88 $\pm$ 10),¹⁶ moderate or severe Sjögren's syndrome-related dry eye (84 $\pm$ 20),¹⁷ long-term type I diabetes mellitus (89 $\pm$ 14),¹⁸ multiple sclerosis (83 $\pm$ 18),²⁵ idiopathic intracranial hypertension (82 $\pm$ 15),¹⁹ or patients who have undergone rhegmatogenous retinal detachment surgery (80 $\pm$ 15).²⁰ The VFQ-25 composite scores were similar to those found in patient groups previously described in the literature with cataract (76 $\pm$ 21),²⁵ keratoconus (75 $\pm$ 17),²¹ macular telangiectasia type 2 (77 $\pm$ 13),²² or patients after Boston keratoprosthesis implantation (72).²³

Participants with ocular trauma resulting in severe vision loss (BCVA $\leq$ 20/200 in the better eye) reported poorer visual quality of life across all subscales. Subscale scores were most depressed for general vision, near vision, driving, and color vision. Difficulty with near vision is not typical in the age group of the study population and warrants additional investigation.

TABLE IV. VFQ-25 Subscale Data Comparison Stratified by Documented Use of Eye Protection

VFQ-25 Subscales	With Eye Protection ($n = 37$)	Without Eye Protection ($n = 14$)	<i>P</i> Value
	Mean $\pm$ SD	Mean $\pm$ SD	
General Health	66.9 $\pm$ 21.3	64.8 $\pm$ 22.7	0.36
General Vision	68.6 $\pm$ 21.8	60.7 $\pm$ 23.6	0.42
Ocular Pain	79.1 $\pm$ 24.3	70.7 $\pm$ 19.2	0.42
Near Activities	80.6 $\pm$ 24.5	67.5 $\pm$ 28.0	0.20
Distance Activities	81.1 $\pm$ 25.7	70.2 $\pm$ 23.3	0.86
Social Function	85.5 $\pm$ 27.2	81.6 $\pm$ 20.8	0.98
Mental Health	79.1 $\pm$ 25.9	66.1 $\pm$ 25.7	0.17
Role Difficulties	81.4 $\pm$ 26.0	67.0 $\pm$ 28.0	0.17
Dependency	86.6 $\pm$ 24.5	78.0 $\pm$ 29.2	0.32
Driving	86.3 $\pm$ 18.2	68.7 $\pm$ 32.6	0.38
Color Vision	89.6 $\pm$ 24.9	92.1 $\pm$ 18.7	0.92
Peripheral Vision	71.5 $\pm$ 30.6	52.3 $\pm$ 31.5	0.11
Composite	80.0 $\pm$ 22.5	70.1 $\pm$ 20.9	0.29

While this study provides evidence that combat ocular trauma is associated with a lower visual quality of life, limitations include the relatively small sample size and the lack of documentation of the use of eye protection at time of injury among participants. It is important to note that confounders were not taken into consideration when comparing the VFQ-25 composite scores to those previously reported in other ocular conditions. These results may not be generalizable to service members who sustain combat ocular trauma in future conflicts as changes in warfare and the combat environment may result in changes to injury patterns in the future. Further research and tracking of visual quality of life outcomes in service members with a history of combat ocular trauma are warranted. Future research should also assess the impact of anatomic location of combat injuries to the eye on the visual quality of life outcomes as this may aid in the design of future eye protection and in the management of combat ocular trauma.

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The Impact of Combat Ocular Trauma and Traumatic Brain Injury on Vision- and Health-Related Quality of Life Among U.S. Military Casualties

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ABSTRACT

Purpose:

The purpose of this study was to assess visual and health-related quality of life (QOL) among U.S. military service members who sustained combat ocular trauma (COT) with or without associated traumatic brain injury (TBI).

Methods:

This was a single-center, prospective observational study of U.S. service members ($n = 88$) with COT who were treated at Walter Reed National Military Medical Center. Participants completed the National Eye Institute Visual Function Questionnaire (VFQ-25) at enrollment and at follow-up (>1 year) and supplemental surveys: Neurobehavioral Symptom Inventory, the Medical Outcomes 36-item Short Form Survey (SF-36), and Mayo-Portland Adaptability Inventory.

Results:

Initial and follow-up VFQ-25 showed a statistically significant increase in median scores for near activities (initial: 75.0, follow-up 83.3; $P = .004$) and peripheral vision (initial: 50.0, follow-up: 75.0; $P = .009$) and in composite scores (initial: 79.5, follow-up: 79.8; $P = .022$). Comparing those who did ($n = 78$) and did not ($n = 8$) have a TBI history, there were no significant differences in median change in VFQ-25 composite scores (with TBI: 2.3 vs. no TBI: 10.7; $P = .179$). Participants with a TBI history had a significantly lower median SF-36 General Health score (with TBI: 67.5 vs. no TBI: 92.5; $P = .009$).

Conclusions:

Vision-related QOL of COT patients is generally good in the long term. However, those with both COT and a history of TBI conditions showed significantly worse functioning in several domains than those without TBI. As TBI is a common finding in COT, this association is an important factor impacting this population's overall clinical presentation and daily functions.

INTRODUCTION

Combat ocular trauma (COT) is a significant cause of morbidity and impairment among U.S. military service members. Although minor eye injuries may result in a temporary decrease in visual acuity (VA), a devastating ocular trauma can end in vision loss. Depending on the mechanism of injury, COT may be accompanied by other systemic injuries, the presence of which could complicate a patient's recovery. Traumatic brain injury (TBI), the so-called signature injury of the casualties in the conflicts in Iraq and Afghanistan, accounts for a significant percentage of polytrauma.¹⁻⁴ According to the DoD and Veterans Brain Injury Center (DVBIC), there were more than 400,000 active duty service members with first-time TBI diagnosis worldwide from 2000 to 2019.⁵ A previous study showed that COT and TBI frequently occur together, with two-thirds of all

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COT associated with TBI.⁶ Visual deficits and dysfunctions in the presence of TBI have been described in the literature;^{7–10} however, the impact of COT and, potentially, the additive effects of TBI on other visual and health aspects of an individual years after injury remain under-reported.

McLaughlin et al.¹¹ initially characterized vision-related quality of life (QOL) among U.S. military service members with COT, and this study further addresses the longitudinal effects by assessing long-term vision-related and health-related QOL measures in U.S. service members with COT with or without a history of TBI.

METHODS

The present report is part of a larger single-center, prospective, observational study of U.S. military service members who sustained ocular injuries during Operations Iraqi Freedom or Enduring Freedom (OIF/OEF) and were evacuated to the former WRAMC and subsequently the Walter Reed National Military Medical Center. Before initiation, the research project was reviewed and approved by the Walter Reed Institutional Review Board and the U.S. Army Medical Research and Materiel Command Human Research Protection Office. Each participant or a legally authorized representative provided informed consent before study participation. Study eligibility included men or women, at least 18 years old, with a history of blast or other combat injury to the head, face, or neck and ocular injury. Individuals who were unwilling or unable to undergo ophthalmologic tests because of mental or physical conditions were excluded from the study. All research was conducted according to the tenets of the Helsinki Declaration. Health Insurance Portability and Accountability Act (HIPAA) compliance was maintained throughout the study.

Information such as patient age, gender, ophthalmic history, mechanism of injury, use of eye protection, and TBI status was obtained either directly from the participants or from their health records. Eye exams including those that were part of standard of care were performed as soon as practical since many of the participants had concomitant injuries. When possible, participants underwent VA assessment, manifest refraction, external eye exam, ocular motility, confrontational visual field, pupil examination, tonometry, slit lamp biomicroscopy, indirect ophthalmoscopy, and ancillary tests. In addition to the clinical tests, the National Eye Institute Visual Function Questionnaire-25 (VFQ-25) was administered during initial evaluation. Re-assessment using the VFQ-25 was performed after at least a year since the initial completion.

As part of a modification to the study, three supplemental QOL questionnaires were added for administration during the study follow-up after a re-consent process: the Neurobehavioral Symptom Inventory (NSI), the Medical Outcomes 36-item Short Form Survey (SF-36), and the Mayo-Portland Adaptability Inventory (MPAI). The NSI assesses neurobehavioral symptoms¹² and is utilized across Military Health System TBI clinics.^{13,14} The SF-36 evaluates health-related QOL measures physical function, role limitations because of

physical health, bodily pain, general health, vitality, social function, role limitations because of emotional health, mental health, and change in overall health.¹⁵ The MPAI facilitates clinical evaluation during post-hospitalization and rehabilitation. In particular, the MPAI Participation Index (M2PI) assesses the recovery after hospital discharge in terms of initiation, social contact, leisure, self-care, independent living, transportation, employment, and financial management.¹⁶

In the VFQ-25, the responses were recoded, ranging from 0 to 100, with higher scores indicating better QOL.¹⁷ Subscales and composite scores were also calculated. On the NSI, the symptoms were rated on a five-point scale ranging from 0 (none; symptom is rarely if ever present/not a problem at all) to 4 (very severe; almost always present and unable to perform at work, school, or home; cannot function without help). The responses were grouped according to the four factor scoring method: somatosensory, affective, cognitive, and vestibular^{13,14} with a higher score indicating greater severity. On the SF-36, responses were rescaled such that each item was scored from 0 to 100. A higher score defined a more favorable health state.¹⁸ Except for the single item health change, all items were grouped and averaged, creating eight subscales. In the MPAI M2PI, the items were rated on a scale of 0 (none) to 4 (severe problems). Raw scores were converted to T-scores with reference to the Mayo sample ratings by people with acute brain injury conversion table provided in the MPAI manual¹⁶ with higher scores corresponding to a greater degree of functional impairment.

The initial questionnaire was administered between 2006 and 2017 and the follow-up questionnaires between 2018 and 2020. The initial VA was the first documented post-injury VA, whereas the final VA was the last documented best-corrected VA. For statistical analysis purposes, the Snellen VA was recoded into five categories based on the VA grading of the Ocular Trauma Score (OTS): (1) no light perception (NLP), (2) light perception or hand motion, (3) 1/200–19/200, (4) 20/200–20/50, and (5) $\geq 20/40$.¹⁹ Enucleated eyes were categorized as NLP.

Analyses only included data collected from participants who completed both initial and follow-up questionnaires ($n = 88$). The Wilcoxon signed rank test was used to test differences between paired responses across the multiple administrations of each test as well as to compare the TBI and non-TBI groups across multiple outcomes. Multivariable linear regression analysis was performed to determine the association between age at injury, years since injury, TBI, the final VA of the worse eye, and measures of QOL, with P -values reported as the result of an ANOVA. Alpha was set at 0.05 for all analyses.

RESULTS

The mean age of the participants at the time of injury was 28.0 ± 7.8 years (range: 18 to 49 years). Of the 88 participants, 86 (97.7%) were male. The participants were re-assessed 9.4 ± 3.0 years from injury (range: 1 to 16 years). Eye injuries

were 70.5% unilateral (62 of 88 participants) and largely because of blast exposure (**Table S1**). Post-injury initial and final VA, as presented in **Table S2**, showed the better eye was seeing $\geq 20/40$ for most of the participants. Seventy-eight (78, 88.6%) of the 88 participants had a history of an associated TBI, with 44 of those TBIs classified as mild (**Fig. S1**). There were no significant differences between those with TBI history and those without in terms of age at time of injury (TBI: 28.1 ± 7.6 years versus non-TBI: 22.8 ± 4.1 years; $P = .053$) and at follow-up survey (TBI: 37.9 ± 8.5 years versus non-TBI: 32.3 ± 4.5 years; $P = .067$). TBI status of two participants was unknown.

Comparing initial and follow-up VFQ-25 responses, there was a statistically significant increase in median scores

for near activities (initial: 75.0, follow-up 83.3; $P = .005$), peripheral vision (initial: 50.0, follow-up: 75.0; $P = .009$) but not for other subscales. The distribution of the initial and follow-up VFQ-25 scores is presented in **Figure 1**. The median composite scores were also different statistically (initial: 79.5, follow-up: 79.8; $P = .023$) with 50% of the participants scoring higher on follow-up.

The NSI-20 and SF-36 scores of the total participants and groups categorized by TBI history are shown in **Tables I** and **II**, respectively. The M2PI mean raw score of the entire cohort was 7 which was equivalent to Mayo T-score of 39. The M2PI scale scores are shown in **Table III**.

Comparing COT patients who did ($n = 78$) and did not have TBI ($n = 8$), there was no significant difference in the median

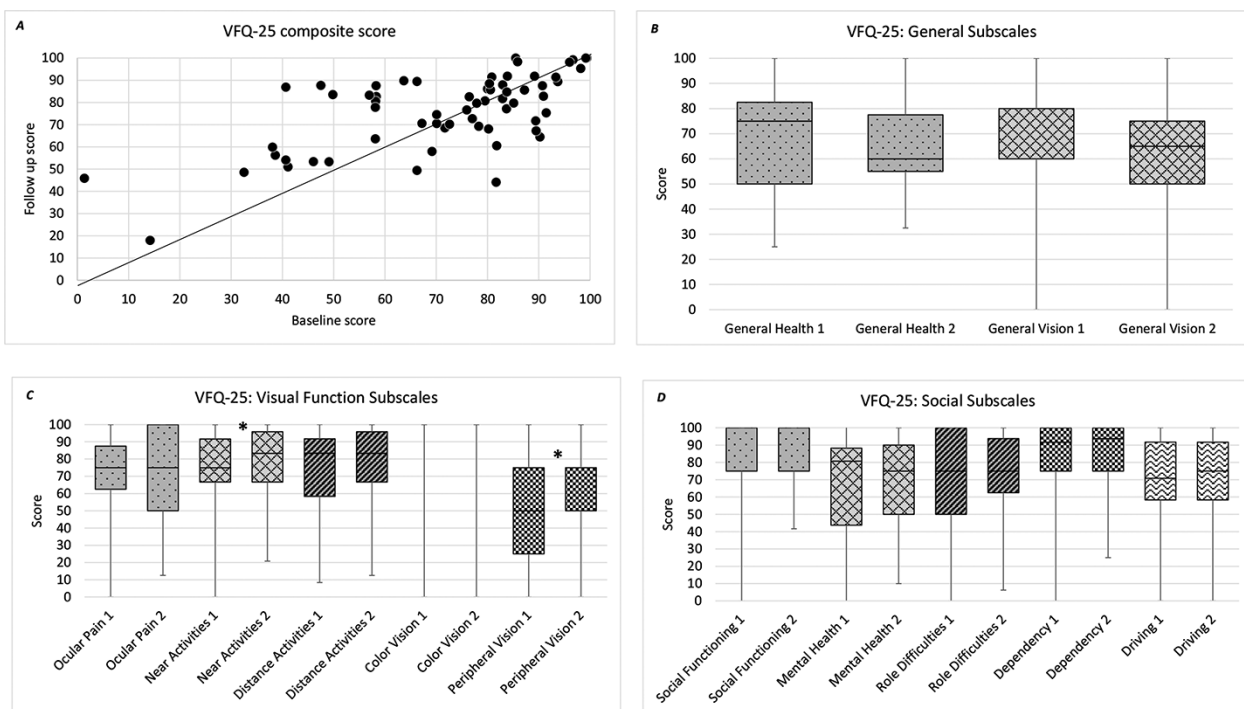


FIGURE 1. Distribution of initial ($n = 71$) and follow-up (at an average of 9.4 ± 3.0 years since injury; $n = 79$) VFQ-25 scores: A, scatterplot of composite scores; B, boxplots of general subscales; C, boxplots of visual function subscales; D, boxplots of social subscales; 1 represents baseline; 2 represents follow-up visit. Asterisk (*) represent statistically significant difference between the initial and final VFQ-25 subscale ($P < .05$).

TABLE I. NSI Subscale and Total Scores at an Average of 9.4 ± 3.0 Years Since Injury

Subscales	Highest possible score ^b	All participants ^a ($n = 88$)		With TBI history ($n = 78$)		No TBI history ($n = 8$)	
		Mean	SD	Mean	SD	Mean	SD
Somatosensory	28	7.6	4.7	7.8	4.7	4.8	4.5
Affective	24	8.0	5.1	8.4	5.1	4.0	3.7
Cognitive	16	5.1	4.0	5.4	4.0	2.3	2.2
Vestibular	12	2.3	2.1	2.5	2.1	0.3	0.5
NSI-20 total score	80	23.0	14.0	24.2	13.9	11.3	9.0

^aTBI status of two participants, unknown;

^bHigher score indicates greater severity.

TABLE II. SF-36 Subscale Scores^b at an Average of 9.4 ±3.0 Years Since Injury and Comparison to the RAND Reference Data¹⁸

Subscales	Present study						Medical outcomes study	
	All participants ^a (n = 88)		TBI (n = 78)		No TBI (n = 8)		RAND (n = 2,471)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Physical function	79.6	21.9	78.31	22.47	91.88	11.00	70.61	27.42
Role limitation because of physical health	52.3	43.7	48.40	43.64	84.38	35.20	52.97	40.78
Role limitation because of emotional health	63.3	44.7	61.54	44.97	70.83	45.21	65.78	40.71
Vitality	52.4	22.9	52.05	23.05	53.13	23.90	52.15	22.39
Mental health	72.3	19.2	71.28	19.28	79.50	18.45	70.38	21.97
Social function	72.0	24.3	70.35	24.27	84.38	23.86	78.77	25.43
Bodily pain	60.9	24.9	58.24	23.99	84.06	20.48	70.77	25.46
General health	63.5	25.1	61.35	24.85	86.88	15.10	56.99	21.11
Health change	51.7	18.9	51.60	19.04	56.25	17.68	59.14	23.12

^aTBI status of two participants, unknown;^bScores ranged from 0 to 100, with higher scores indicating better quality of life.**TABLE III.** MPAI M2PI Subscale Scores at an Average of 9.4 ±3.0 Years Since Injury

Subscales	Highest possible score	All participants ^a (n = 88)		With TBI history (n = 78)		No TBI history (n = 8)	
		Mean	SD	Mean	SD	Mean	SD
Initiation	4	1.22	1.21	1.9	1.23	0.86	1.07
Social contact	4	1.28	1.32	1.37	1.34	0.43	0.54
Leisure	4	1.22	1.32	1.33	1.34	0.14	0.38
Self-care	4	0.41	0.78	0.46	0.82	0.00	0.00
Independent living	4	0.68	1.12	0.76	1.16	0.14	0.38
Transportation	4	0.51	1.14	0.51	1.14	0.14	0.38
Paid employment	4	0.89	1.51	1.00	1.57	0.00	0.00
Other employment	4	1.09	1.11	1.26	1.10	0.00	0.00
Financial management	4	0.60	1.47	0.57	1.30	0.00	0.00
Raw score ^b	30	6.8	5.9	7.2	5.9	2.5	3.3
Mayo T-score	91	43		43		33	

^aTBI status of two participants, unknown.^bTwo subscale items were rescored then raw scores were summed and converted to T-scores with reference to Mayo sample ratings by people with acute brain injury conversion table provided in the MPAI manual (MPAI manual). Higher T-scores suggest greater limitations.

change in VFQ-25 composite scores from initial to follow-up survey (with TBI: 2.3 vs. no TBI: 10.7; $P = .179$). However, the interpretation of this non-significant result is challenged by low statistical power because of the small number of non-TBI participants. Despite this low sample size, the participants who had TBI showed significantly lower median SF-36 General Health score (with TBI: 67.5 vs. no TBI: 92.5; $P = .005$). Those with TBI history also had higher median NSI-20 score (with TBI: 23.5 vs. no TBI: 12.5; $P = .009$) and M2PI raw score (with TBI: 6 vs. no TBI: 2; $P = .011$).

Multivariable regression analyses showed that VFQ-25 scores on follow-up were predicted by the final VA of the worse eye ($P = .001$), but not by age at injury, length of time since injury, or TBI history. Visual acuity of 20/40 or better in the worse eye was significantly associated with higher VFQ-25 scores. Age at injury and TBI history predicted scores on the NSI-20 ($P = .04$). Consistent with the bivariate analysis, TBI predicted M2PI T-score ($P = .035$) and SF-36 General Health score ($P = .019$), but not by the other factors. Further analyses showed that among those who had history of TBI,

classifying severity into two groups (either mild TBI or moderate, severe and penetrating TBI) did not predict scores on the VFQ-25 ($P = .642$), NSI-20 ($P = .808$), M2PI ($P = .107$) and SF-36 General Health ($P = .564$) at follow-up.

DISCUSSION

The prominence of unconventional munitions such as improvised explosive devices in recent conflicts has given rise to a different pattern of injury among U.S. military casualties. Blast exposure on this battlefield has resulted in varying degrees of blunt and penetrating trauma involving multiple body systems including the head, neck, and face. Operation Iraqi/Operation Enduring Freedom saw higher rates of COT compared to previous wars.²⁰ The frequency of blast events in these conflicts has also pointed to a significant number of TBI cases among individuals wounded by hostile forces.²¹ It is therefore not surprising that TBI is one of most common non-ocular injuries associated with COT.⁶ In the present study, different blast mechanisms accounted for almost 70% of the participants' injuries. Most of the participants had unilateral eye involvement and a vast majority of them had TBI. Although 93% of the participants had relatively good VA of the better eye (best corrected VA $\geq 20/40$), the injuries, whether directly or indirectly, seemed to have a measurable impact on their functional status and general well-being over time.

After an average of nine years since injury, vision-related QOL measures as assessed by VFQ-25 were mostly unchanged. Participants appeared to have less difficulty dealing with peripheral vision and performing near activities since injury; however, outcomes based on other parameters such as general vision, ocular pain, distance activities, color vision, social functioning, mental health, role difficulties, dependency, driving, and general health seemed to be no different from the initial survey. When examining VFQ-25 composite scores (initial: 79.5, follow up: 79.8; $P = .023$), our findings suggest that vision-related QOL seem to improve with half of the population having higher scores on follow-up. Comparing those with and without TBI history, the improvement in scores from initial to follow-up did not seem to be any different statistically although this finding had statistical power issues because of the small sample size of the non-TBI group. Multivariate regression analyses suggest that the overall vision-related QOL may be influenced by the final VA of the worse eye but not by other predictors. Those who have VA of 20/40 or better in the worse eye are likely to have better outcomes which could probably be because of essentially intact binocular vision. Although general physical and mental QOL measures of monocular patients are not significantly different from binocular patients',²² those with monocular vision have visual deficits such as limited peripheral vision and loss of depth perception.^{22,23}

Assessing post-concussive symptoms over time is an important aspect of clinical treatment in patients with TBI. In the present study, the result of the NSI showed that

participants with a history of TBI had higher scores and experienced a greater degree of symptoms compared to those without TBI. Additionally, those with a history of TBI had the most difficulty with affective symptoms (e.g., headaches, fatigue, difficulty falling, or staying asleep; feeling anxious or depressed; and irritability or poor frustration tolerance), whereas those with no history of TBI were most affected by somatosensory symptoms, where vision problems would normally be reflected. Of note, the final VA of the better eye was $\geq 20/40$ for all non-TBI participants; thus, factors other than VA seemed to play a role in these symptoms. A multivariate regression model suggests that older age at the time of injury and TBI is significantly associated with higher NSI-20 scores on follow-up.

The evaluation of everyday functioning and a return to community participation in patients with visual impairments and debilitating injuries is as important as symptom monitoring. In our study, the SF-36 General Health scores were significantly lower in participants with TBI compared to those with no TBI, indicating a less favorable health state. However, when compared to the published normative data by RAND,¹⁸ the scores were generally comparable. Nonetheless, those with COT and TBI tended to have lower scores for role limitations because of physical health, role limitations because of emotional health, vitality, social function, bodily pain, and health change.

Assessing the study cohort using the M2PI also showed significant differences between those with and without a history of TBI. Participants with TBI history had a significantly higher median raw score vs. those who did not have an injury with co-occurring TBI which could indicate that those with TBI history had greater functional limitations compared to those without. The findings of the studies by Waid-Ebbs et al.²⁴ and O'Rourke et al.²⁵ however suggested that self-reported M2PI scores should be carefully interpreted especially if applied for policy-making, diagnoses, and treatment recommendations.

There are a few limitations to the generalization of the results in this study. The small sample size of the non-TBI group greatly limited the statistical power in comparing the TBI and non-TBI cohorts. The small sample size of the study overall also hindered comparison across TBI severity and types of eye injuries. Those who had more severe TBI would generally be expected to have more persistent difficulties than those with milder TBI but this was not evident when explored using regression analyses. Sampling bias could have potentially occurred as the individuals recruited and enrolled were likely patients with injuries severe enough to require hospital admission or close and frequent follow-ups. The timeframes for the final VA and the administration of the follow-up survey were also highly variable. Additionally, as the focus of present analysis was on ocular trauma, no group with a history of TBI and no COT were included. Therefore, we cannot conclude whether there is an additive effect such that those with both conditions do worse than those with a history of TBI

alone. Polytrauma is associated with pain, PTSD, and other conditions that can contribute to additive clinical and functional difficulties.²⁶ Although the relationship between TBI and other bodily injuries is a complex one, facial injuries tend to be associated with the highest PTSD and neurobehavioral difficulty scores.²⁷ This study, limitations notwithstanding, highlights the significance of monitoring symptoms and functional status over time as sequelae may persist in the long term.

CONCLUSIONS

Combat ocular trauma affects patients and vision-related QOL with some aspects such as peripheral vision and near activities appearing to improve over time since injury. Combat ocular trauma patients with TBI history seem to experience greater functional limitations and neurobehavioral symptoms years after injury compared to those without. The results of the study suggest VA of the worse eye, age at the time of injury, and TBI status are important factors that could have an impact upon the QOL in patients with COT in the long term. The study also underscores the importance of a strong support system, both in health care and the community, and more importantly, the need to develop ways and means to further protect service members in combat. Future studies need to further evaluate and compare QOL measures of COT patients with different severities of TBI.

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SUPPLEMENTARY MATERIAL

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CONFLICT OF INTEREST STATEMENT

No conflicting relationship exists for any author on this paper.

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Open-globe injuries: A global issue of protection

This month's *Clinical and Experimental Ophthalmology* highlights an untimely, unfortunate and unnerving clinical condition that presents to our busy emergency departments. Court et al wonderfully describe the circumstances surrounding eye injuries and subsequent treatments undertaken to prevent vision loss from the injury in the study "Visual and ocular morbidity in severe open-globe injuries presenting to a regional eye centre in New Zealand."¹ Whether the patient suffers an injury following an altercation with another person, power equipment, vehicle or as the result of warfare, the challenges faced remain the same, and the visual outcomes are highly variable and are predicted most characteristically by the injury itself. Despite the small surface area covered by the globe, it is interesting to note the frequency of ocular injuries and the severity the injuries cause. Small, sharp objects seem to have a knack for striking an unprotected eye and result in globe devastation. A 1999 review of the World Health Organization's Blindness Data Bank demonstrated that 55 million people suffer activities of daily living impacting eye injuries annually, whereas over 1 million people are blinded.² Understanding the barriers of eye protection when performing activities that put the eye at risk is critical for us as vision scientists to influence meaningful public awareness and policy to reduce morbidity-associated ocular trauma.

Ocular injuries do not discriminate based on age, gender or nationality. They are ubiquitous. As the authors note, there are behavioural and situational factors that increase the incidence of ocular trauma. It is known that ocular injuries tend to occur more frequently in young people and during high-risk occupational activities (hammering metal on metal, grinding metal, etc.).³ We must direct public awareness and policy in a flexible manner so that citizens understand the why as much as the how and when. The experience of the US military in managing injuries sustained as a result of conflict during the past 20 years highlights the potential benefit that mandatory eye protection plays in the prevention of ocular injury.⁴⁻⁶ Prior to the Global War on Terror, the US military learned that the decision for military members to wear eye protection was multifactorial and included the individual, the environment, the organization and a soldier's peer group. During the earliest stages of the conflicts in Afghanistan and Iraq, military-issued eye protection was bulky, ugly

and prone to fog or becoming dirty. Leaders understood these limitations and did not enforce eye protection to the same degree as other protective equipment. After several minor eye injuries resulted in personnel requiring evacuation to the United States and long recoveries, units quickly recognized the barriers to effective eye protection usage and implemented plans to improve compliance. In addition, aggressive educational programmes influenced the desire to comply with eye protection requirements. In short, it became a matter of life, death, teamwork and mission success to ensure eye protection compliance. As a result, the incidence of ocular injury relative to combat activities diminished and eye protection compliance vastly improved over the last decade.

While the barriers to compliance with eye protection in the home and workplace are probably similar in the civilian sector, the ability to enforce compliance must be handled in much different ways. When considering occupational exposures to injury, there is evidence that the issuance of financial penalties to companies involved in workplace injuries results in a reduced incidence of reported ocular injury. A review of Workman's Compensation claims in the state of Kentucky, USA, over a 10-year period indicated a reduction in ocular injury beginning in 2000, when financial penalties for workplace injuries increased substantially.⁷ Nonetheless, eye protection compliance remains a burden to the individual. Many of the same challenges the US military faced in attempting to force compliance is evident in industrial workers.⁸ Bulky and prone to fogging appears to be a barrier, whereas clear, work-related risk and education level appear to encourage compliance.

Hoskin et al, in a recent review on the history of eye protection, report a trend away from occupational exposures and towards recreational or accidental events.⁹ Although employers and employees begin to understand the importance of eye protection in the performance of their day-to-day activities, other situations may require an individual to self-regulate or recognize the potential for ocular injury. The risk of ocular injury is well documented in sports such as squash, tennis, badminton and basketball. The list, however, is almost endless, and nearly every sport carries some risk of ocular injury.¹⁰ Nonetheless, eye protection standards for sports is highly variable and less well enforced.



Interestingly, eye injuries appear to be the lowest in older cohorts compared to younger cohorts.¹¹ This is likely due to the recognition of the risk involved, acceptance of visual degradation that may come from the use of eye protection and social acceptance. Thus, efforts targeted at youth ocular injury prevention and protection should focus on school-based athletics and rule modification to mandate compliance with eye protection. Moreover, enlisting the support of the entertainment industry to sway youth and young adults could be an approach worth evaluating further. An interesting series of analyses demonstrated that television and media could contribute to the ambivalent attitude towards eye protection.^{12,13} It is impossible to say whether eye protection compliance would improve if Dwayne “The Rock” Johnson or Tom Cruise wore eye protection in all of their action scenes. However, it does indicate to us, as vision scientists, where our patients obtain their information, or at least how they modify their style and behaviour patterns.

One deep gap that remains, even with these strategies, is in protecting/supporting at-risk populations, such as immigrants and foreigners. These individuals present to emergency departments in a disproportionate amount and are typically less likely to wear eye protection than others.¹⁴ Court et al identify this risk factor in New Zealand, and anecdotally, similar trends appear in the United States as well. As Court et al point out, immigrant populations tend to take jobs that may include more opportunity to sustain ocular injury; are less likely to wear eye protection due to cost, lack of knowledge or lack of availability; and present later due to disparities in care. In many countries, immigration status may limit protections for an immigrant that may be available to other citizens and allows for an opportunity for an employer to neglect or ignore compliance with safety standards.

Because the unusual situation of ocular trauma occurs with champagne corks, fish hooks, curling irons and scissors, basic strategies can be implemented to significantly reduce the incidence of ocular injuries and the morbidity associated with these. Critically, employers and employees need to be educated on the importance of eye protection. Furthermore, children, adolescents, adults and sports-governing entities must recognize the need for protective eyewear in sports. Finally, we must expand outreach and education to at-risk populations, whose access to information and appropriate equipment remain substantial public health threats.

CONFLICT OF INTEREST

None declared.

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Complex ocular trauma outcomes and system capabilities: lessons from a combat zone and implications for national eye trauma care

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In this month's issue, Gensheimer, Blanch, and Kerber detail the US–UK experience of ophthalmic support to NATO combat operations in Afghanistan from 2017 to 2019. They describe patterns of eye injuries, procedures, and outcomes, and remark on opportunities for future improvement [1]. The manuscript is unique in that it includes epidemiology and outcomes of care for Host National (HN) casualties, an aspect that is often lost in the well-documented reports of expeditionary force casualties over the last two decades [2–4]. Specifically, the authors cite a 44% rate of retinal detachment in HN after open globe repair, and visual outcomes that are equally poor for blast-concussed closed globe injuries and ruptures, results that stand in contrast to coalition outcomes from similar wounds. Given the marked disparities in ocular care and capabilities available to NATO casualties once repatriated vs. those available to HN casualties, the corresponding disparity in outcomes comes as no surprise. This provides a basis for future study. In addition, beyond the authors own conclusions, the article provides a springboard for deep reflection on the nature, character, and increasing frequency of complex ocular polytrauma and the care systems required for optimal treatment (both expeditionary and at home), the appropriate level of ophthalmic sophistication in combat theaters, the application of military medical rules of engagement, and the critical reliance on international cooperation to augment resources in caring for complex ocular polytrauma in vulnerable HN populations.

The United States Department of Defense (US DOD) delineates moral and legal responsibilities for care of HN during combat operations. DOD Instruction 6200.07 unambiguously defines specific obligations when encountering HN casualties, including requirements to provide direct health

care and “appropriate treatment to the extent practical...[to] professional judgements and standards similar to those applied to the treatment of military services in comparable circumstances, *particularly in situations that would otherwise likely result in loss of life, limb, or eyesight*” [emphasis added] [5]. Authors operated under this directive. That the US DOD recognizes the critical importance of eyesight as a life-altering injury is telling, and underscores the criticality of having ophthalmologists present in any combat theater; yet that need has recently come under scrutiny by allied Defense agencies [6, 7]. While the proportion of HN to coalition force care will understandably shift with the tempo of combat operations—certainly this article reports a much higher proportion than prior studies [8], consistent with the decreasing numbers of deployed allied troops—recognition of the contingency for significant HN care must be recognized and deliberately considered in the planning for deployed care capability since the conclusions will inevitably affect personnel, equipment, training and logistics, and ultimately access to care and outcomes. Analogies and parallel concerns can be easily made to domestic civilian ocular trauma care.

Of particular note, the article highlights the disparity when deployed ophthalmologists were required to perform a variety of definitive surgeries on HN casualties because more sophisticated care was unavailable locally, rather than damage control ophthalmology performed on evacuable coalition casualties. They adhere to moral and legal responsibilities to deliver “comparable care” within significant limitations of inadequate equipment, personnel and supplies, and personal abilities (often operating solo and outside of their subspecialty) while facing horrific injuries. Most notably—as the most sophisticated ophthalmic resource available for the HN population—they acted to prevent further visual morbidity despite the invariable pattern of complex ocular polytrauma that typically requires a coordinated team of ocular subspecialists with state-of-the-art equipment to prevent blindness. That level of care is available to repatriated casualties after evacuation but is absent in combat zones. This invites the question of defining appropriate surgical capabilities for theater care in the

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inevitable future war, particularly if evacuation is lacking or significantly delayed even for coalition casualties.

Given limited health care resources, we must search broadly for answers to the problem of optimal trauma care in various settings. As an international community, we must fill new and longstanding vacuums of capability and resources at *systems levels* to reduce the burden of blindness from military trauma and conflicts. A similar challenge exists for peacetime trauma care nationally. To begin this, we must first recognize and agree that a need exists. This article goes to the heart of that gap. Further, efforts to prevent or reduce the burden of ocular trauma and disease must be considered. Establishing formal local, regional, or national referral networks for ongoing care may be a valuable consideration if needed capabilities are limited in local areas. Creating a system to efficiently manage modern ocular injuries—they're not just complicated, they're *complex*—which require a coordinated milieu of subspecialists (including rehabilitation services) is not easy, but it is essential [9, 10]. Such a system, designed to ensure the right patient arrives at the *right facility with the right ocular capability* for the right treatment at the right time, would benefit both military and civil care. This article captures those global challenges in the setting of warzone Afghanistan, with its limited ophthalmologic assets, challenging geographic constraints, large distances, and multifaceted cultural factors.

The authors further discuss the potential for eye protection ("eyepro") in preventing injury in noncombatant populations. Several military publications have demonstrated its effectiveness in reducing the incidence and severity of combat ocular trauma [11, 12]. In particular, Parker highlights the dramatic disparity in rates of injury between NATO forces (wearing eyepro; low incidence) and embedded Afghan National forces (not wearing eyepro; high incidence, often bilateral) [13]. How to increase availability and compliance for these protective measures is an issue not exclusive to combat ocular trauma but germane to society as a whole.

The authors are to be congratulated on their diligence and compassion in attempting to bring state-of-the-art ocular trauma care to a desperately needful population in exceptionally trying circumstances. That outcomes were perhaps not as satisfying as might be achieved elsewhere is no fault of theirs. Lacking the needed sophisticated system of ocular trauma care, one does his or her best. A lasting impact is also made in identifying the need, and this article goes a long way toward that end.

Disclaimer

The opinions or assertions contained herein are the private ones of the author/speaker and are not to be construed as

official or reflecting the views of the United States Army, Department of Defense, the Uniformed Services University of the Health Sciences or any other agency of the U.S. Government.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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INVITED EDITORIAL

MILITARY MEDICINE, 185,11/12:487, 2020

Department of Defense and Eye Injury Data: Shedding New Light

LTC Marcus H. Colyer, MC*

This month's issue of *Military Medicine* presents the results of the first peer-reviewed manuscript composed of outcomes data from the Defense and Veterans Eye Injury and Vision Registry (DVEIVR), a congressionally directed registry to track diagnoses, interventions, and follow-up each significant eye injury of active-duty personnel and managed by the Department of Defense and Veterans Administration's Vision Center of Excellence (VCOE).¹ The VCOE established the DVEIVR 10 years ago as one of its primary efforts and is now realizing the results of the effort. Currently, DVEIVR is used to revise clinical practice guidelines that are data- and experience-driven, inform clinical leaders of emerging threats and opportunities, and support the Vision Research Program's \$20 million annual research portfolio. The fact that DVEIVR was finally queried and published useful outcomes data is an important milestone in understanding the all-case visual outcomes in this cohort and highlights critical gaps in provider documentation to ensure valid information in clinical records.

DVEIVR was conceptualized in the years 2009 and 2010 as a response to the National Defense Authorization Act of 2008. As a part of the act, the Department of Defense and VCOE was tasked to create a "registry of information for the tracking of the diagnosis, surgical intervention or other operative procedure, other treatment, and follow-up for each case of significant eye injury incurred by a member of the Armed Forces while serving on active duty."² Data entry commenced in January 2012. DVEIVR abstractors have analyzed over 32,000 service members' significant eye injuries, with over 178,000 unique encounters abstracted to date. The untapped potential that exists is significant, and could have major benefits to understanding patterns associated with traumatic

vision loss. The manuscript describes the methods to categorize over 25,000 unique patients abstracted within the DVEIVR according to visual outcome and presence/severity of traumatic brain injury (TBI). The total analysis included 3,573 subjects, or 14% of all subjects registered within DVEIVR. The study concluded that TBI status does not correlate with severe vision loss, while eye injury severity does. The more valuable output, considering that this is the first query of DVEIVR, is that 86% of subjects identified as having eye injuries and registered in DVEIVR are still missing the most critical primary clinical outcome measure—visual acuity. This absence of data may be the result of several gaps. The most unlikely scenario is that patients identified as meeting DVEIVR inclusion criteria are not receiving ophthalmic care. Alternatively, the patients may experience an eye injury, but the patient receives care entirely outside the Military Health System and is inaccessible to the DVEIVR abstractors. Another scenario is that subjects defined as significant eye injury may not have any eye injury at all. For example, patients who experience photophobia, it may reveal that the DVEIVR case definition of "significant eye injury", which includes photophobia without overt injury to the eye or adnexa, is broad when compared to other tracking systems. DVEIVR considers conditions such as corneal abrasion, post-concussion visual symptoms (photophobia, reading difficulty, and accommodative dysfunction for example) as "significant eye injuries" in order to characterize cohorts that suffer from these conditions. Conversely, in a recent publication from the Joint Theater Trauma Registries (JTTR), Breeze et al.³ identified only 5,769 of 67,586 (8%) casualties from Iraq and Afghanistan who suffered eye injuries. The case definition of "significant eye injury" in JTTR is based upon general criteria that include the presence of injury to specific structures of the eye (retina, cornea, lens), loss of one or both eyes, or cranial nerve injury following injury. Although it is possible that there are $\times 5$ the number of eye injuries in training, garrison, off duty, or other situations, it is also highly plausible that the case definition for "significant eye injury" in the JTTR and DVEIVR are sufficiently dissimilar, and JTTR is capable of abstracting more completely a smaller and more defined case definition. In reality, it is likely that all of these factors are at play when attempting to meet the Congressional intent of the

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[†]The opinions or assertions contained herein are the private ones of the author/speaker and are not to be construed as official or reflecting the views of the Department of Defense, the Uniformed Services University of the Health Sciences or any other agency of the U.S. Government.

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DVEIVR and to publish outcomes from DVEIVR data that are valid and meaningful.

Additionally, the methods necessary to develop clean cohorts are complex and resource-intensive. This complexity owes, in part, to the variation in documentation within the optometry and ophthalmology subspecialty communities across the Military Health System as well as ineffective education with respect to the standardized classification of ocular trauma. Apostolova et al.⁴ previously outlined the underlying data structure of DVEIVR and one approach to identify cohorts. In the present publication, Singman identified the cohorts based upon a combination of visual acuity recordings and ICD-9 codes. Categorization based solely upon acuity numbers simplified the cohorts greatly and is information that is not otherwise easily accessible. However, visual acuity is not a structured data field in the legacy military medical record (AHLTA and Essentris), so this required manual abstraction of 25,000 patient records to achieve this result. A more valuable and scalable solution will be to standardize documentation methods for ocular trauma and enforce required fields, such as visual acuity and intraocular pressure measurements on all patients with specific conditions. The ophthalmology and optometry communities in both the Department of Defense and Veterans Administration are united in this effort, but are constrained by fiscal constraints and conflicting programmatic requirements. Further, validated trauma classification frameworks should be incorporated into the documentation tools to ensure accurate, consistent, and reproducible data abstracts are achieved with minimal reanalysis. Meanwhile, one of the most valuable but absent components of DVEIVR and the MHS medical documentation systems is the access, storage, retrieval, and analysis of ophthalmic device modalities—ie photos, ultrasound videos, optical coherence tomography, and visual field data. These data elements offer a potential for machine learning and artificial intelligence not fully considered when the DVEIVR was initially conceptualized a decade ago. The potential for a longitudinal trend of hundreds of patient images meeting specific criteria develop the concept of “imaging biomarkers” following ocular trauma, where the natural history of a patient could not only be recorded with traditional structured exam elements, but also with images or visual field changes. The old adage, “A picture tells 1000 words” is valid in ophthalmology and ophthalmic trauma more than anywhere else. With effective integration of ophthalmic imaging into a registry like DVEIVR, treatment paradigms can be more effectively analyzed, coordination can be achieved

at levels previously unimagined, and the true intent of the Congressional directive can be met.

Lastly, the conclusion drawn from this publication with respect to the link between visual system dysfunction and TBI is a controversy that has challenged the vision community for a generation. The visual system contains both afferent and efferent components and pathology can result from any number of insults along the pathway. Similarly, the factors involved in development of TBI as well as the phenotypes that result are variable with some features involving the visual system and others that do not. One sensitive marker of TBI is change in extraocular motility function—specifically saccades and pursuits. However, these changes do not manifest in reduction in visual acuity or constriction of visual fields. Unfortunately, the objective assessment of saccades and pursuits is poorly defined and even less well documented by clinicians. As such, this study can state that there is no association between vision loss and TBI, but cannot tell us how much or little association there is with visual system dysfunction. Specifically, there remains a gap in our knowledge of patient-reported visual symptoms and physiologic correlates. Without clearer understanding of anatomic locations or structure–function correlations to the symptoms that patients experience, we continue to chase this problem.

It has taken considerable effort to align the data, the system, the researcher, and the results in order to produce this manuscript, and the author’s successes are commendatory. The military ophthalmology and optometry communities recognize the achievements made through the publication of data arising from the DVEIVR. Further analysis and refinements in the data architecture will undoubtedly result in additional clinically meaningful outcomes. Continued efforts to query and publish vision-related information following trauma may lead to closing the wide gap that exists with understanding the causes of and impacts of vision loss on active-duty service members.

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National Eye Institute
Visual Functioning Questionnaire - 25
(VFQ-25)

version 2000

(SELF-ADMINISTERED FORMAT)

January 2000

RAND hereby grants permission to use the "National Eye Institute Visual Functioning Questionnaire 25 (VFQ-25) July 1996, in accordance with the following conditions which shall be assumed by all to have been agreed to as a consequence of accepting and using this document:

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The following is a survey with statements about problems which involve your vision or feelings that you have about your vision condition. After each question please choose the response that best describes your situation.

Please answer all the questions as if you were wearing your glasses or contact lenses (if any).

Please take as much time as you need to answer each question. All your answers are confidential. In order for this survey to improve our knowledge about vision problems and how they affect your quality of life, your answers must be as accurate as possible. Remember, if you wear glasses or contact lenses, please answer all of the following questions as though you were wearing them.

INSTRUCTIONS:

1. In general we would like to have people try to complete these forms on their own. If you find that you need assistance, please feel free to ask the project staff and they will assist you.
2. Please answer every question (unless you are asked to skip questions because they don't apply to you).
3. Answer the questions by circling the appropriate number.
4. If you are unsure of how to answer a question, please give the best answer you can and make a comment in the left margin.
5. Please complete the questionnaire before leaving the center and give it to a member of the project staff. Do not take it home.
6. If you have any questions, please feel free to ask a member of the project staff, and they will be glad to help you.

STATEMENT OF CONFIDENTIALITY:

All information that would permit identification of any person who completed this questionnaire will be regarded as strictly confidential. Such information will be used only for the purposes of this study and will not be disclosed or released for any other purposes without prior consent, except as required by law.

Visual Functioning Questionnaire - 25

PART 1 - GENERAL HEALTH AND VISION

1. In general, would you say your overall health is:

(Circle One)

Excellent 1
Very Good 2
Good 3
Fair 4
Poor..... 5

2. At the present time, would you say your eyesight using both eyes (with glasses or contact lenses, if you wear them) is excellent, good, fair, poor, or very poor or are you completely blind?

(Circle One)

Excellent 1
Good 2
Fair 3
Poor..... 4
Very Poor..... 5
Completely Blind..... 6

3. How much of the time do you worry about your eyesight?

(Circle One)

- None of the time 1
- A little of the time 2
- Some of the time 3
- Most of the time 4
- All of the time? 5

4. How much pain or discomfort have you had in and around your eyes (for example, burning, itching, or aching)? Would you say it is:

(Circle One)

- None 1
- Mild 2
- Moderate 3
- Severe, or 4
- Very severe? 5

PART 2 - DIFFICULTY WITH ACTIVITIES

The next questions are about how much difficulty, if any, you have doing certain activities wearing your glasses or contact lenses if you use them for that activity.

5. How much difficulty do you have reading ordinary print in newspapers? Would you say you have:

(Circle One)

- No difficulty at all 1
- A little difficulty 2
- Moderate difficulty 3
- Extreme difficulty 4
- Stopped doing this because of your eyesight 5
- Stopped doing this for other reasons or not interested in doing this 6

6. How much difficulty do you have doing work or hobbies that require you to see well up close, such as cooking, sewing, fixing things around the house, or using hand tools? Would you say:

(Circle One)

No difficulty at all 1
A little difficulty..... 2
Moderate difficulty 3
Extreme difficulty 4
Stopped doing this because of your eyesight 5
Stopped doing this for other reasons or not
interested in doing this 6

7. Because of your eyesight, how much difficulty do you have finding something on a crowded shelf?

(Circle One)

No difficulty at all 1
A little difficulty..... 2
Moderate difficulty 3
Extreme difficulty 4
Stopped doing this because of your eyesight 5
Stopped doing this for other reasons or not
interested in doing this 6

8. How much difficulty do you have reading street signs or the names of stores?

(Circle One)

No difficulty at all 1
A little difficulty..... 2
Moderate difficulty 3
Extreme difficulty 4
Stopped doing this because of your eyesight 5
Stopped doing this for other reasons or not
interested in doing this 6

9. Because of your eyesight, how much difficulty do you have going down steps, stairs, or curbs in dim light or at night?

(Circle One)

- No difficulty at all 1
A little difficulty..... 2
Moderate difficulty 3
Extreme difficulty 4
Stopped doing this because of your eyesight 5
Stopped doing this for other reasons or not
interested in doing this 6

10. Because of your eyesight, how much difficulty do you have noticing objects off to the side while you are walking along?

(Circle One)

- No difficulty at all 1
A little difficulty..... 2
Moderate difficulty 3
Extreme difficulty 4
Stopped doing this because of your eyesight 5
Stopped doing this for other reasons or not
interested in doing this 6

11. Because of your eyesight, how much difficulty do you have seeing how people react to things you say?

(Circle One)

- No difficulty at all 1
A little difficulty..... 2
Moderate difficulty 3
Extreme difficulty 4
Stopped doing this because of your eyesight 5
Stopped doing this for other reasons or not
interested in doing this 6

12. Because of your eyesight, how much difficulty do you have picking out and matching your own clothes?

(Circle One)

No difficulty at all 1
A little difficulty..... 2
Moderate difficulty 3
Extreme difficulty 4
Stopped doing this because of your eyesight 5
Stopped doing this for other reasons or not
interested in doing this 6

13. Because of your eyesight, how much difficulty do you have visiting with people in their homes, at parties, or in restaurants ?

(Circle One)

No difficulty at all 1
A little difficulty..... 2
Moderate difficulty 3
Extreme difficulty 4
Stopped doing this because of your eyesight 5
Stopped doing this for other reasons or not
interested in doing this 6

14. Because of your eyesight, how much difficulty do you have going out to see movies, plays, or sports events?

(Circle One)

No difficulty at all 1
A little difficulty..... 2
Moderate difficulty 3
Extreme difficulty 4
Stopped doing this because of your eyesight 5
Stopped doing this for other reasons or not
interested in doing this 6

15. Are you currently driving, at least once in a while?

(Circle One)

Yes..... 1 Skip To Q 15c

No 2

15a. IF NO: Have you never driven a car or have you given up
driving?

(Circle One)

Never drove..... 1 Skip To Part 3, Q 17

Gave up..... 2

15b. IF YOU GAVE UP DRIVING: Was that mainly because of your
eyesight, mainly for some other reason, or because of both your
eyesight and other reasons?

(Circle One)

Mainly eyesight..... 1 Skip To Part 3, Q 17

Mainly other reasons..... 2 Skip To Part 3, Q 17

Both eyesight and other reasons 3 Skip To Part 3, Q 17

15c. IF CURRENTLY DRIVING: How much difficulty do you have
driving during the daytime in familiar places? Would you say
you have:

(Circle One)

No difficulty at all 1

A little difficulty..... 2

Moderate difficulty..... 3

Extreme difficulty..... 4

16. How much difficulty do you have driving at night? Would you say you have:

(Circle One)

- No difficulty at all 1
A little difficulty..... 2
Moderate difficulty 3
Extreme difficulty 4
Have you stopped doing this because
of your eyesight 5
Have you stopped doing this for other
reasons or are you not interested in
doing this 6

- 16A. How much difficulty do you have driving in difficult conditions, such as in bad weather, during rush hour, on the freeway, or in city traffic? Would you say you have:

(Circle One)

- No difficulty at all 1
A little difficulty..... 2
Moderate difficulty 3
Extreme difficulty 4
Have you stopped doing this because
of your eyesight 5
Have you stopped doing this for other
reasons or are you not interested in
doing this 6

PART 3: RESPONSES TO VISION PROBLEMS

The next questions are about how things you do may be affected by your vision. For each one, please circle the number to indicate whether for you the statement is true for you all, most, some, a little, or none of the time.

READ CATEGORIES:	(Circle One On Each Line)				
	All of the time	Most of the time	Some of the time	A little of the time	None of the time
17. <u>Do you accomplish less</u> than you would like because of your vision?	1	2	3	4	5
18. <u>Are you limited</u> in how long you can work or do other activities because of your vision?.....	1	2	3	4	5
19. How much does pain or discomfort <u>in or around</u> <u>your eyes</u> , for example, burning, itching, or aching, keep you from doing what you'd like to be doing? Would you say:	1	2	3	4	5

For each of the following statements, please circle the number to indicate whether for you the statement is definitely true, mostly true, mostly false, or definitely false for you or you are not sure.

(Circle One On Each Line)

	Definitely True	Mostly True	Not Sure	Mostly False	Definitely False
20. I <u>stay home most of the time</u> because of my eyesight.	1	2	3	4	5
21. I feel <u>frustrated</u> a lot of the time because of my eyesight.	1	2	3	4	5
22. I have <u>much less control</u> over what I do, because of my eyesight.	1	2	3	4	5
23. Because of my eyesight, I have to <u>rely too much on</u> <u>what other people tell me...</u>	1	2	3	4	5
24. I <u>need a lot of help from</u> others because of my eyesight.	1	2	3	4	5
25. I worry about <u>doing things</u> <u>that will embarrass myself</u> <u>or others</u> , because of my eyesight.	1	2	3	4	5

Mayo-Portland Adaptability Inventory-4

Participation Index (M2PI)

Muriel D. Lezak, PhD, ABPP & James F. Malec, PhD, ABPP

Name: _____ Clinic # _____ Date _____

Person reporting (circle one): Single Professional Professional Consensus Person with brain injury Significant other: _____

Below each item, circle the number that best describes the level at which the person being evaluated experiences problems. Mark the greatest level of problem that is appropriate. Problems that interfere rarely with daily or valued activities, that is, less than 5% of the time, should be considered not to interfere. Write comments about specific items at the end of the rating scale.

1. Initiation: Problems getting started on activities without prompting				
0 None	1 Mild problem but does <u>not</u> interfere with activities; may use assistive device or medication	2 Mild problem; interferes with activities 5-24% of the time	3 Moderate problem; interferes with activities 25-75% of the time	4 Severe problem; interferes with activities more than 75% of the time
2. Social contact with friends, work associates, and other people who are not family, significant others, or professionals				
0 Normal involvement with others	1 Mild difficulty in social situations but maintains normal involvement with others	2 Mildly limited involvement with others (75-95% of normal interaction for age)	3 Moderately limited involvement with others (25-74% of normal interaction for age)	4 No or rare involvement with others (less than 25% of normal interaction for age)
3. Leisure and recreational activities				
0 Normal participation in leisure activities for age	1 Mild difficulty in these activities but maintains normal participation	2 Mildly limited participation (75-95% of normal participation for age)	3 Moderately limited participation (25-74% of normal participation for age)	4 No or rare participation (less than 25% of normal participation for age)
4. Self-care: Eating, dressing, bathing, hygiene				
0 Independent completion of self-care activities	1 Mild difficulty, occasional omissions or mildly slowed completion of self-care; may use assistive device or require occasional prompting	2 Requires a little assistance or supervision from others (5-24% of the time) including frequent prompting	3 Requires moderate assistance or supervision from others (25-75% of the time)	4 Requires extensive assistance or supervision from others (more than 75% of the time)
5. Residence: Responsibilities of independent living and homemaking(such as meal preparation, home repairs and maintenance, personal health maintenance beyond basic hygiene including medical management) but not including managing money (see # 8)				
0 Independent; living without supervision or concern from others	1 Living without supervision but others have concerns about safety or managing responsibilities	2 Requires a little assistance or supervision from others (5-24% of the time)	3 Requires moderate assistance or supervision from others (25-75% of the time)	4 Requires extensive assistance or supervision from others (more than 75% of the time)
6. *Transportation				
0 Independent in all modes of transportation including independent ability to operate a personal motor vehicle	1 Independent in all modes of transportation, but others have concerns about safety	2 Requires a little assistance or supervision from others (5-24% of the time); cannot drive	3 Requires moderate assistance or supervision from others (25-75% of the time); cannot drive	4 Requires extensive assistance or supervision from others (more than 75% of the time); cannot drive

7A. *Paid Employment: Rate either item 7A or 7B to reflect the primary desired social role. Do not rate both. Rate 7A if the primary social role is paid employment. If another social role is primary, rate only 7B. For both 7A and 7B, “support” means special help from another person with responsibilities (such as, a job coach or shadow, tutor, helper) or reduced responsibilities. Modifications to the physical environment that facilitate employment are not considered as support.

0 Full-time (more than 30 hrs/wk) without support	1 Part-time (3 to 30 hrs/ wk) without support	2 Full-time or part-time with support	3 Sheltered work	4 Unemployed; employed less than 3 hours per week
--	--	--	-------------------------	--

7B. *Other employment: Involved in constructive, role-appropriate activity other than paid employment.

Check only one to indicate primary desired social role:

Childrearing/care-giving Homemaker, no childrearing or care-giving Student
 Volunteer Retired (Check retired only if over age 60; if unemployed, retired as disabled and under age 60, indicate “Unemployed” for item 7A.

0 Full-time (more than 30 hrs/wk) without support; full-time course load for students	1 Part-time (3 to 30 hrs/ wk) without support	2 Full-time or part-time with support	3 Activities in a supervised environment other than a sheltered workshop	4 Inactive; involved in role-appropriate activities less than 3 hours per week
--	--	--	---	---

8. Managing money and finances: Shopping, keeping a check book or other bank account, managing personal income and investments

0 Independent, manages money without supervision or concern from others	1 Manages money independently but others have concerns	2 Requires mild assistance or supervision from others (5-24% of the time)	3 Requires moderate assistance or supervision from others (25-75% of the time)	4 Requires extensive assistance or supervision from others (more than 75% of the time)
--	---	--	---	---

Comments:

Item # _____

Items with an asterisk (6, 7A or 7B) require rescoring as specified below before raw scores are summed and referred to reference tables to obtain standard T-scores.

Rescore item 6. Original score = _____

If original score = 0 or 1, new score = 0

If original score = 2 or 3, new score = 1

If original score = 4, new score = 3

Rescore item 7A or 7B. Original score = _____

If original score = 0, new score = 0

If original score = 1 or 2, new score = 1

If original score = 3 or 4, new score = 3

New score for item 6 = _____

New score for item 7A or 7B = _____

Sum of scores for other items (1-5 & 8) = _____

TOTAL = _____ Standard T-score = _____



36-Item Short Form Survey Instrument (SF-36)

RAND 36-Item Health Survey 1.0 Questionnaire Items

Choose one option for each questionnaire item.

1. In general, would you say your health is:

- ☐ 1 - Excellent
 - ☐ 2 - Very good
 - ☐ 3 - Good
 - ☐ 4 - Fair
 - ☐ 5 - Poor
-

2. **Compared to one year ago**, how would you rate your health in general **now**?

- ☐ 1 - Much better now than one year ago
 - ☐ 2 - Somewhat better now than one year ago
 - ☐ 3 - About the same
 - ☐ 4 - Somewhat worse now than one year ago
 - ☐ 5 - Much worse now than one year ago
-

The following items are about activities you might do during a typical day. Does **your health now limit you** in these activities? If so, how much?

	Yes, limited a lot	Yes, limited a little	No, not limited at all
3. Vigorous activities , such as running, lifting heavy objects, participating in strenuous sports	☐ 1	☐ 2	☐ 3
4. Moderate activities , such as moving a table, pushing a vacuum cleaner, bowling, or playing golf	☐ 1	☐ 2	☐ 3
5. Lifting or carrying groceries	☐ 1	☐ 2	☐ 3
6. Climbing several flights of stairs	☐ 1	☐ 2	☐ 3
7. Climbing one flight of stairs	☐ 1	☐ 2	☐ 3
8. Bending, kneeling, or stooping	☐ 1	☐ 2	☐ 3
9. Walking more than a mile	☐ 1	☐ 2	☐ 3
10. Walking several blocks	☐ 1	☐ 2	☐ 3
11. Walking one block	☐ 1	☐ 2	☐ 3
12. Bathing or dressing yourself	☐ 1	☐ 2	☐ 3

During the **past 4 weeks**, have you had any of the following problems with your work or other regular daily activities **as a result of your physical health?**

- | | Yes | No |
|---|-----------------------|-----------------------|
| 13. Cut down the amount of time you spent on work or other activities | ☐ | ☐ |
| | 1 | 2 |
| 14. Accomplished less than you would like | ☐ | ☐ |
| | 1 | 2 |
| 15. Were limited in the kind of work or other activities | ☐ | ☐ |
| | 1 | 2 |
| 16. Had difficulty performing the work or other activities (for example, it took extra effort) | ☐ | ☐ |
| | 1 | 2 |
-

During the **past 4 weeks**, have you had any of the following problems with your work or other regular daily activities **as a result of any emotional problems** (such as feeling depressed or anxious)?

- | | Yes | No |
|--|-------------------------|-------------------------|
| 17. Cut down the amount of time you spent on work or other activities | ☐ 1 | ☐ 2 |
| 18. Accomplished less than you would like | ☐ 1 | ☐ 2 |
| 19. Didn't do work or other activities as carefully as usual | ☐ 1 | ☐ 2 |
-

20. During the **past 4 weeks**, to what extent has your physical health or emotional problems interfered with your normal social activities with family, friends, neighbors, or groups?

- ☐ 1 - Not at all
 - ☐ 2 - Slightly
 - ☐ 3 - Moderately
 - ☐ 4 - Quite a bit
 - ☐ 5 - Extremely
-

21. How much **bodily** pain have you had during the **past 4 weeks**?

- ☐ 1 - None
 - ☐ 2 - Very mild
 - ☐ 3 - Mild
 - ☐ 4 - Moderate
 - ☐ 5 - Severe
 - ☐ 6 - Very severe
-

22. During the **past 4 weeks**, how much did **pain** interfere with your normal work (including both work outside the home and housework)?

- ☐ 1 - Not at all
 - ☐ 2 - A little bit
 - ☐ 3 - Moderately
 - ☐ 4 - Quite a bit
 - ☐ 5 - Extremely
-

These questions are about how you feel and how things have been with you **during the past 4 weeks**. For each question, please give the one answer that comes closest to the way you have been feeling.

How much of the time during the **past 4 weeks**...

	All of the time	Most of the time	A good bit of the time	Some of the time	A little of the time	None of the time
23. Did you feel full of pep?	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6
24. Have you been a very nervous person?	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6
25. Have you felt so down in the dumps that nothing could cheer you up?	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6
26. Have you felt calm and peaceful?	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6
27. Did you have a lot of energy?	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6
28. Have you felt downhearted and blue?	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6
29. Did you feel worn out?	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6
30. Have you been a happy person?	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6
31. Did you feel tired?	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6

32. During the **past 4 weeks**, how much of the time has **your physical health or emotional problems** interfered with your social activities (like visiting with friends, relatives, etc.)?

- ☐ 1 - All of the time
 - ☐ 2 - Most of the time
 - ☐ 3 - Some of the time
 - ☐ 4 - A little of the time
 - ☐ 5 - None of the time
-

How TRUE or FALSE is **each** of the following statements for you.

	Definitely true	Mostly true	Don't know	Mostly false	Definitely false
33. I seem to get sick a little easier than other people	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
34. I am as healthy as anybody I know	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
35. I expect my health to get worse	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
36. My health is excellent	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

ABOUT

The RAND Corporation is a research organization that develops solutions to public policy challenges to help make communities throughout the world safer and more secure, healthier and more prosperous. RAND is nonprofit, nonpartisan, and committed to the public interest.



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DoD

IRB NUMBER: 20263

IRB APPROVAL DATE: 01/08/2018

Neurobehavioral Symptom Inventory (NSI)

Please rate the following symptoms with regard to how much they have disturbed you IN THE LAST 2 Weeks.
The purpose of this inventory is to track symptoms over time. Please do not attempt to score.

0 = None – Rarely if ever present; not a problem at all

1 = Mild – Occasionally present, but it does not disrupt my activities; I can usually continue what I'm doing; doesn't really concern me.

2 = Moderate – Often present, occasionally disrupts my activities; I can usually continue what I'm doing with some effort; I feel somewhat concerned.

3 = Severe – Frequently present and disrupts activities; I can only do things that are fairly simple or take little effort; I feel I need help.

4 = Very Severe – Almost always present and I have been unable to perform at work, school or home due to this problem; I probably cannot function without help.

Symptoms	0	1	2	3	4
Feeling Dizzy	☐	☐	☐	☐	☐
Loss of balance	☐	☐	☐	☐	☐
Poor coordination, clumsy	☐	☐	☐	☐	☐
Headaches	☐	☐	☐	☐	☐
Nausea	☐	☐	☐	☐	☐
Vision problems, blurring, trouble seeing	☐	☐	☐	☐	☐
Sensitivity to light	☐	☐	☐	☐	☐
Hearing difficulty	☐	☐	☐	☐	☐
Sensitivity to noise	☐	☐	☐	☐	☐
Numbness or tingling on parts of my body	☐	☐	☐	☐	☐
Change in taste and/or smell	☐	☐	☐	☐	☐
Loss of appetite or increased appetite	☐	☐	☐	☐	☐
Poor concentration, can't pay attention, easily distracted	☐	☐	☐	☐	☐
Forgetfulness, can't remember things	☐	☐	☐	☐	☐
Difficulty making decisions	☐	☐	☐	☐	☐
Slowed thinking, difficulty getting organized, can't finish things	☐	☐	☐	☐	☐
Fatigue, loss of energy, getting tired easily	☐	☐	☐	☐	☐
Difficulty falling or staying asleep	☐	☐	☐	☐	☐
Feeling anxious or tense	☐	☐	☐	☐	☐
Feeling depressed or sad	☐	☐	☐	☐	☐
Irritability, easily annoyed	☐	☐	☐	☐	☐
Poor frustration tolerance, feeling easily overwhelmed by things	☐	☐	☐	☐	☐

Date:

Name:

Medical Record #: