The Cornea after Primary Blast Trauma

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Abstract
Purpose: This study examined the seemingly uninjured eye of soldiers with blast injuries involving the head, face, and fellow eye to obtain insight into primary blast ocular injuries.

Methods: Serial exams were performed on nineteen U.S. Army Soldiers with a combat-related blast injury involving the head, face and either eye for effects of primary blast trauma in the clinically unaffected eye. Outcome measures included corrected distance visual acuity (CDVA), endothelial cell density (ECD), corneal hysteresis (CH), corneal resistance factor (CRF), cornea compensated intraocular pressure (IOPcc), and central corneal thickness (CCT). The Wilcoxon signed ranks test was used to compare initial versus final values.

Results: CDVA improved over the course of follow up: median logMAR -0.04 (-0.12 to 0.16) to -0.12 (-0.18 to 0.12), p = 0.015. There were no significant changes for either ECD or CCT over time. Of the 19 patients, 10 had measurements of CH, CRF, IOPcc, and CCT, with no significant changes over time. Median CH and CRF were lower than reported in the literature.

Conclusions: In this case series, ocular health in terms of ECD, IOPcc, and CCT did not change over time after exposure to primary blast injury. CH and CRF were noted to be lower than averages reported in the literature. Direct injury from secondary blast injury remains the most significant threat to the eye but longitudinal studies are recommended to determine the long term prognosis of eyes exposed to blast shock waves.

Keywords
Primary ocular blast injury, Trauma, Cornea, Endothelial cell count

Abbreviations

Introduction
Insurgents are changing the face of modern warfare by using unconventional tactics and creating increasingly dangerous explosive devices. The use of improvised explosive devices (IEDs), rocket propelled grenades (RPGs), mines, mortars, and suicide vests are exposing a larger number of soldiers and civilians to devastating blasts. These blasts render varying types of injuries characterized as primary, secondary, tertiary or quaternary depending on the mechanism of injury. Multisystem injuries are common due to the damaging force of explosives, and the potential and severity for these are dependent on size, environment, and distance from the explosive source [1-3].

The eye, although less than 1% of the body surface area, is also at risk of injury [1]. Traditionally ocular blast injuries have been characterized as primary or secondary injuries. Secondary blast injuries result from penetration of fragmentary projectiles dispersed by the blast and are the most frequent cause of ocular injuries [1-6]. Ocular trauma due to penetration of the cornea by supersonic debris is well-established, but the effects due to primary blast injuries are less well-known. Primary blast injuries (PBI) result from a pressure differential created by the passage of the blast wave. It is this wave that delivers the primary injury upon its impact with body tissues. The blast wave can interact with the body in two ways causing either stress damage or shear damage [8]. Stress damage occurs at the interface of body tissues of differing densities and waves travelling through differing media may have their path altered by the density gradient. Injury is most severe at the surface and as the wave continues through tissue shedding energy, it causes spall-like stress damage and shearing resulting in tissue disruption [7,9-12]. Transverse shearing waves are responsible for damage such as globe rupture due to compression and deformation [8,9].

Some instances of ocular PBI may go unnoticed due to the morbidity of a blast or the lack of a visually significant injury. A study modeling PBI showed that the structure and shape of the eye as well...
as the differing interfaces are ideal for propagating the pressure wave. Using the model, structures posterior to the vitreous base were shown to bear higher pressures from PBI compared to the cornea resulting in retinal and optic nerve damage [13]. Vascular and neural damage to the retina may be more easily detected than the cornea through which the differing interfaces are ideal for propagating the pressure wave. The purpose of this study was to observe the cornea in the seemingly uninjured eye of Soldiers exposed to a blast for PBI.

Methods

U.S. Army Soldiers with a combat related blast injury enrolled in an ongoing Walter Reed Army Medical Center Institutional Review Board approved study underwent standard anterior segment testing, when possible, at the Ophthalmology service, Walter Reed Army Medical Center, Washington, D.C. Participants in this limited series were included if they had a monocular injury and were serially examined after sustaining a blast injury to the head, face and eye. Data for analysis included age, gender, injury, use of protective eyewear, and duration of follow up. Measurement of corrected distance visual acuity (CDVA) and corneal measurements of the seemingly uninjured eye were analyzed. Corneal evaluation included the following: automated endothelial cell density (ECD), central corneal thickness (CCT), corneal hysteresis (CH), corneal resistance factor (CRF), and cornea compensated intraocular pressure (IOPcc).

Corrected distance visual acuity (CDVA)

CDVA was assessed using a projector-type Snellen chart viewed at a distance equivalent to 20 feet (6 meters). Best optical correction was determined by refractionometry using a manual mechanical phoropter (Reichert Ophthalmic Instruments Inc., Depew, NY). Snellen acuity results were converted to logarithm of the minimum angle of resolution (logMAR) for data analysis.

Central corneal thickness (CCT)

CCT measurements were obtained using the minimum corneal thickness value as measured by the Orbscan II corneal topography (Orbtek, Bausch & Lomb, Salt Lake City, UT) or the pachymetry map using the anterior segment optical coherence tomography (AS OCT) System (Visante, Carl Zeiss Meditec Inc., Dublin, CA).

Endothelial cell density (ECD)

Endothelial cells were imaged and counted using the Confoscan 4 confocal microscope (Nidek Inc., Fremont, CA). ECD scans were performed using a 40x lens and analyzed using the CS4 NAVIS (Nidek Advanced Vision Information System). A region of interest (ROI) was selected to include the area of cells most suitable for automated ECD analysis. Automatic cell counts of selected ROI were manually edited to optimize identification and counting of cells. Data generated included ECD and the morphometric indices of polygonomath (degree of change in cell area), and pleomorph (variation in cell shape based on percentage of hexagonal cells).

Analysis

Statistical analyses of initial and final results for CDVA, ECD, CCT, CH, CRF, and IOPcc were performed using SPSS version 16.0 for windows (IBM Corp., Armonk, NY). A Wilcoxon signed-ranks test was used to compare the initial and final values. A Mann-Whitney test was used to compare the use of eye protection, and associated head or face injury in terms of the change in CDVA, ECD, polygonomath, pleomorph, CH, CRF, IOPcc, and CCT. A p-value of < 0.05 was considered statistically significant. Data are presented as median and range, unless otherwise indicated.

Results

Nineteen male Soldiers with a mean age of 28.8 ± 8.2 years (range 22 to 50) had measurements taken on average 124 ± 149 days (range 7 to 600) post injury. The follow up visit averaged 425 ± 340 days (range 115 to 1393) post injury. Table 1 presents an overview of injury findings. Blast trauma was caused by IEDs in 79% of patients (15 patients), mortars in 11% (two patients), RPGs in 5% (one patient), and mines in 5% (one patient). The use of eye protection at the time of injury was confirmed by 26% of injured soldiers (five patients), not worn by 42% (eight patients), and unknown in 32% (six patients).

<table>
<thead>
<tr>
<th>Number</th>
<th>Age</th>
<th>Mechanism of Injury</th>
<th>Eye Protection</th>
<th>Outcome in fellow eye</th>
<th>Head or Face Injury</th>
<th>Initial Visit (days)</th>
<th>Final Visit (days)</th>
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<tr>
<td>1</td>
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<td>536</td>
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*Improvised Explosive Device
†Intraocular Foreign Body
‡Rocket Propelled Grenade

Table 1: Overview of injury findings.
Table 2 summarizes the clinical characteristics at the initial and final follow up. CDVA improved over the course of follow up: LogMAR -0.04 (-0.12 to 0.18) to -0.12 (-0.18 to 0.12), \( p = 0.015 \). The average number of endothelial cells analyzed in this study was 57 (37-94) at the initial visit and 61 (37-93) at the final visit.

In the subset comparing patients wearing eye protection (+ eye pro; \( n = 5 \)) to those not wearing eye protection (- eye pro; \( n = 8 \)), as self-reported, there was a significant difference in the initial CDVA logMAR + eye pro 0.00 (0.00 to 0.11); - eye pro logMAR -0.10 (-0.12 to -0.03) \( p = 0.003 \) and final CDVA logMAR + eye pro -0.10 (-0.11 to 0.01); - eye pro logMAR -0.12 (-0.12 to -0.08) \( p = 0.030 \). There were no other significant differences at the initial or final visits \( p > 0.17 \) when comparing CDVA, ECD polymegathism, pleiomorphism, CH, CRF, IOPcc, and CCT between those wearing and not wearing eye protection.

Comparing patients with associated head or face injuries (\( n = 14 \)) to those without (\( n = 5 \)), there were no significant differences in initial or final ECD, polymegathism, pleiomorphism, CH, CRF, IOPcc, and CCT \( p > 0.10 \). There was a significant difference in initial CDVA \( p = 0.003 \) but not final \( p = 0.11 \). Comparing the subset of patients seen within ten days of injury (\( n = 4 \)) to those seen later (\( n = 15 \)), there were no significant differences in any measures at the initial visit or final visit in CDVA, ECD, polymegathism, pleiomorphism, CH, CRF, IOPcc, and CCT.

Discussion

The force and injury associated with a blast is substantial. Facial structures, specifically nasal and brow ridges, reflect and focus blast waves amplifying pressure on the eye [14]. Furthermore, orbital geometry and diverse ocular tissue interfaces generate and channel opposing stress waves that contribute to eye damage [13].

We examined corneal morphology to describe the consequences of primary blast in the eyes of patients exposed to blast injury with trauma to the fellow eye.

Variability in morphometry of the cornea may indicate injury and the drastic pressure change from primary blast injury (PBI) has been shown to be capable of disrupting the delicate arrangement of corneal cell layers [7,15-18]. The variation in cell size of normal people is less than 32% while the proportion of normal hexagonal shaped cells is greater than 60% [19]. This study found polymegathism within the normal range at both the initial and final follow up. Pleiomorphism, however, was just under the 60% normal range at 59.3% at the initial visit and 56.7% at the final visit. A limitation of the study is the lack of significant visual complaint, longitudinal follow up would be needed to determine if this decrease in biomechanics becomes significant.

Eye armor has been shown by Bailoor et al. to be effective in reducing blast wave penetration and decreasing the resulting pressure load on the eye [14]. Some variability may be attributed to the difficulty in obtaining optimal scans in participants due to trauma in the fellow eye. However, without significant visual complaint, longitudinal follow up would be needed to determine if this decrease in biomechanics becomes significant.

Conclusion

Corrected distance visual acuity did improve statistically during the study which may be attributed to improved systemic health (improved mental status, resolution of associated facial injuries, decreasing narcotic pain management) over the study period. However, in this small cohort of patients, corneal measurements of CH and CRF were observed to be below the averages reported in the literature. These findings emphasize the importance of ongoing follow-up to determine the significance and long-term prognosis of eyes exposed to primary blast as corneal PBI may not be easily detected.

References


