Protective Equipment

Computational Model of the Eye for Primary and Secondary Blast Trauma

Ocular trauma is one of the most common types of combat injuries resulting from the exposure of Service Members to improvised explosive devices (IEDs). However, the injury mechanism associated with the primary blast wave remains mostly unknown. For example, the magnitude and character of the stresses and strains (e.g., shear, tension) in the tissues of the eye caused by the blast wave are not well understood, nor are the factors that determine the distribution of the blast overpressure (BOP) to the eye. Moreover, the criteria for mechanical and functional damage to important ocular structures are unknown. Under the auspices of a grant funded by the Vision Research Program managed by the Congressionally Directed Medical Research Program (CDMRP), the research team at the Johns Hopkins University (JHU) Mechanical Engineering Department has developed a computational model of primary blast injury to the eye. The model includes fluid-structure calculation of the interaction of the blast wave with the facial features of a typical 21 year old male without eye-protection and with spectacles or goggles. The model also included a detailed model of a deformable eye with physiological representation of the main internal ocular structures of the eye, spatially varying thickness of the cornea-scleral shell, and nonlinear tissue properties. The model was applied to calculate the intraocular pressure and stress state of the eye-wall and internal ocular structure caused by different blast conditions. Researchers have found that the facial features have an important effect of amplifying the blast pressure loading on the eye for certain blast conditions.[1] Goggles were significantly better than spectacles at reducing the maximum pressure loading on the eye, but goggles trapped the high pressure blast wave in front of the eye for significantly longer duration than spectacles. The consequence of this prolonged exposure to a lower level pressure loading to the eye versus that incurred by the short duration pressure peak is unknown. The simulations also found the highest tensile and compressive stresses at the fovea and optic nerve head, which may be consistent with choroidal hemorrhaging, retinal detachment and damage, and optic nerve damage.[2] The distortional stresses were highest in the sclera at the attachment with the extra ocular tissues. The simulation outcomes where applied to three different injury models. Two of the models were developed for blunt impact injuries to the eye and the third was developed from in vitro experiment of blast loading to porcine eyes. Different injury models produced widely different injury risk. This finding highlights the need for integrated modeling and experimental studies to evaluate mechanical and functional damage to the ocular structures caused by blast loading. Such an integrated study would provide specimen-specific correlation of the blast conditions, level of tissue-specific stress magnitude, and functional and/or mechanical damage. This model is expected to enable the development of improved protective devices for the eye and surrounding tissues. Enhanced protective devices have the potential to reduce long-term morbidity from ocular injuries for the Service Member.

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1 Bailoor, S., Bhardwaj, R., & Nguyen, T. D. (2015). Effectiveness of eye armor during blast loading. Biomechanics and Modeling in Mechanobiology, 14(6), 1227–1237. https://doi.org/10.1007/s10237-015-0667-z

2 Bhardwaj, R., Ziegler, K., Seo, J. H., Ramesh, K. T., & Nguyen, T. D. (2014). A computational model of blast loading on the human eye. Biomechanics and Modeling in Mechanobiology, 13(1), 123–140. https://doi.org/10.1007/s10237-013-0490-3