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Biomechanical modeling of eye trauma for different orbit anthropometries

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ABSTRACT

In military, automotive, and sporting safety, there is concern over eye protection and the effects of facial anthropometry differences on risk of eye injury. The objective of this study is to investigate differences in orbital geometry and analyze their effect on eye impact injury. Clinical measurements of the orbital aperture, brow protrusion angle, eye protrusion, and the eye location within the orbit were used to develop a matrix of simulations. A finite element (FE) model of the orbit was developed from a computed tomography (CT) scan of an average male and transformed to model 27 different anthropometries. Impacts were modeled using an eye model incorporating lagrangian–eulerian fluid flow for the eye, representing a full eye for evaluation of omnidirectional impact and interaction with the orbit. Computational simulations of a Little League (CD25) baseball impact at 30.1 m/s were conducted to assess the effect of orbit anthropometry on eye injury metrics. Parameters measured include stress and strain in the corneoscleral shell, internal dynamic eye pressure, and contact forces between the orbit, eye, and baseball. The location of peak stresses and strains was also assessed. Main effects and interaction effects identified in the statistical analysis illustrate the complex relationship between the anthropometric variation and eye response. The results of the study showed that the eye is more protected from impact with smaller orbital apertures, more brow protrusion, and less eye protrusion, provided that the orbital aperture is large enough to deter contact of the eye with the orbit.

1. Introduction

There are over 1.9 million eye injuries annually in the U.S., including over 9000 globe ruptures and 30,000 cases of blindness resulting from trauma (McGwin et al., 2005; Parver, 1986; Smith et al., 2002). Motor vehicle crashes (Anderson et al., 2002; Duma and Crandall, 2000; Duma et al., 2002, 1996, 2005; Fukagawa et al., 1993; Kuhn et al., 1994; Lehto et al., 2003; Lueder, 2000; Muller-Jensen and Allmaras, 1969; Rao et al., 2008), military operations (Biehl et al., 1999; Colyer et al., 2008; Heier et al., 1993; Mader et al., 1993, 2006; Thach et al., 2008; Weichel et al., 2008), and ocular impacts with sporting equipment and consumer products (Bullock et al., 1997; Cassen, 1997; Chisholm, 1969; Hecker, 2007; Pardhan et al., 1995; Rodriguez et al., 2003; Thach et al., 1999; Vinger et al., 1997) are common causes of eye injuries. In motor vehicle crashes, severe eye injury can result from impact with an airbag, flying glass, or foam particles from the vehicle's dashboard. In military operations, projectile or goggle loading can result in severe eye injuries. Frequent agents of blunt trauma in sports include baseballs, golf balls, tennis balls, paintballs, and hockey sticks.

In military, automotive, and sporting safety, there is concern over eye protection for different individuals. There are significant differences in orbit shape and size, as well as eye placement, between persons of different gender, age, and ethnicity (Ahmadi et al., 2007; Barretto and Mathog, 1999; Bolanos Gil de Montes et al., 1999; Dunsky, 1992; Pessa and Chen, 2002; Pessa et al., 1999; Pivnick et al., 1999; Pryor, 1969; van den Bosch et al., 1999). These anthropometric differences are suspected to affect the response of the eye when subjected to a traumatic impact. A previous study using FE analysis to investigate orbital deformation found two types of orbital distortion (horizontal and rotational) and reported orbital stresses for different types of blunt impact (Al-Sukhun et al., 2006). To the authors' knowledge, previous experimental eye impact tests and computational simulations have not investigated the effect of variations in orbit anthropometry on the risk of globe rupture. The objective of the current study is to model differing orbital anthropometries and eye placement to study the biomechanical response of an eye subjected to a blunt impact. Simulation results will explain eye injury risk variation across individuals and are valuable to the design of eye protection equipment.

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