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Dynamic Response Characteristics of an Ocular Model under Shock Waves

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Extended Abstract

Abstract

Blast-related ocular injuries are increasingly prevalent in modern warfare and industrial incidents. Even when fragments are blocked, blast shock waves can penetrate ocular protection, propagate within the globe, and induce intraocular damage; however, intraocular shock-wave propagation mechanisms and biomechanical injury thresholds remain insufficiently defined, limiting protective design and clinical decision-making. In this study, a biomimetic eye–orbit physical loading model was developed based on human globe–orbit anatomy and tissue mechanical properties, using hydrogel materials and 3D printing. The model was installed in a double-diaphragm shock tube to perform graded overpressure tests, and the macroscopic deformation response was captured by high-speed imaging. A corresponding finite element model incorporating the cornea–sclera shell, ciliary body, lens, vitreous body, and retina was then established, with experimentally measured pressure–time histories applied as boundary conditions to quantify stress–strain distributions in intraocular tissues. Experiments revealed a characteristic "compression–rebound–oscillation" response of the globe, with increasing peak overpressure leading to larger deformation amplitudes, prolonged rebound/oscillation duration, and more severe surface wear. Simulations indicated early stress concentration in the cornea upon shock arrival, followed by rapid intraocular pressure rise due to the low compressibility of the lens and intraocular media; the pressure wave subsequently propagated posteriorly along the anteroposterior axis, sequentially loading the lens and retina, with structure-specific stress–strain signatures.

Limitations arise from simplified material properties, idealized structural layering and boundary conditions, and inter-individual variability. Future work will develop higher-fidelity physical and numerical models via multi-material 3D printing and advanced hydrogel biomimetics, and establish multiscale coupled biomechanical–pathological frameworks to better link shock loading, tissue deformation, and clinical manifestations.

Keywords:

ocular injury blast shock wave biomechanics finite element analysis injury criterion