Coupled Modeling for Investigation of Blast Induced Traumatic Brain Injury

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ABSTRACT

Modeling of human body biomechanics resulting from blast exposure is very challenging because of the complex geometry and the substantial material heterogeneity in the human body. We have developed a detailed finite element model (FEM) of the human body which represents both the geometry and the material realistically [1]. The model includes the detailed head (face, skull, brain, cerebrospinal fluid, and spinal cord), the skeleton, air cavities such as lungs, as well as other tissues.

This computational model has been used to accurately simulate the stress wave propagation in the human body under various loading conditions. The blast loading on human model has been generated by simulating C4 explosions, via a novel combination of 1-D and 3-D computational fluid dynamics (CFD) formulations. An interface was developed to apply the blast pressure loading on the human skin from the CFD simulation. The explicit solvers developed for FEM and CFD systems are highly scalable and capable of solving large systems. The computational meshes generated for these simulations are of good quality and can use relatively large time step sizes without resorting to the artificial time scaling treatment. By employing this coupled Eulerian-Lagrangian fluid structure interaction (FSI) approach we obtained the parametric response of the human brain during the blast wave impact. This coupled gas dynamics and biomechanics solution approach has been validated against recent shock tube testing data using physical phantom and small animals [2].

In this paper, we develop the methodology to solve the strong coupling between CSF and surrounding tissue at fluid-solid interface. We utilize an improved anatomy and mesh for the head, and appropriate material properties for the CSF, skeleton, and tissues in the improved coupled FSI solver. We present biomechanical response of the brain considering the effects of cerebrospinal fluids (CSF) and tissue material properties, and inclusion of the torso. The mesh-based Eurerian-Lagrangian FSI solver approach is computationally expensive in the iterative coupling process and can have the mesh distortion problem during large deformations. We will present the details of the new unified solver approach based on the material point method (MPM) we have developed to overcome these problems.

A key contribution of the unified solver in this paper is that it can solve both fluid and structural dynamics simultaneously except that fluid and solid follow different constitutive laws. We compare the accuracy and efficiency of the unified approach with the mesh-based coupled Eulerian-Lagrangian solver. We demonstrate and discuss the potentials of the MPM methodology by simulating the head CSF-tissue interaction under the blast loading, as well as other similar complex FSI applications. These results suggest that the computational models and techniques developed here could be used to predict human biomechanical responses in blast events, and help design the protection against the blast induced TBI.

REFERENCES

[1] Tan, X.G., Przekwas, Gupta R.K., Macro-micro biomechanics finite element modeling of brain injury under concussive loadings, IMECE2016-66218, Proceedings of the ASME 2016 International Mechanical Engineering Congress & Exposition.

[2] Tan, X.G., Przekwas, A.J., Long, J.B., Validations of Virtual Animal Model for Investigation of Shock/Blast Wave TBI, IMECE 2013-64587, Proceedings of the ASME 2013 International Mechanical Engineering Congress & Exposition.