A Computational Approach to Soft-Tissue Fluid-Structure Interaction

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Abstract:

Motivation

Cerebral disorders affect millions of people around the world. Despite progress in science and medicine, accurate diagnosis and treatment of brain related diseases is hampered due to the lack of proper understanding of the pathophysiology of such disorders. The fluid-soft tissue interaction problem is fundamental in addressing open challenges crucial for the understanding of intracranial dynamics. The challenge includes quantifying mechanical interactions of the expanding cerebral vasculature and the soft tissues of the brain. In this study, we present the mathematical framework to solve the governing system of equations of the fluid-structure interaction (FSI) problem using numerical techniques [1].

Methodology

The fluid and solid transport equations of mass and momentum are transformed into a moving, body-fitted coordinate system using generalized curvilinear coordinates [2]. We extend the mapping relationships by computing the motion of conformal reference coordinate system relative to a fixed observer. The model incorporates Eulerian-Lagrangian method to consistently track sharp deformable interfaces between the fluid and solid.

The equations describing fluid-structure interaction are coupled and consist of a nonlinear system of partial differential equations (PDEs). The governing PDEs are discretized using the finite volume method in both structured and unstructured meshes [3]. Simultaneous solution approach using inexact Newton method for the non-linear system and a Krylov subspace based method for the linear subsystem (GMRES method) was used instead of fixed-point iteration methods like SIMPLE algorithm [1].

Broader Impact

FSI has important applications in biomedical engineering. One such application includes quantification of the multi-dimensional flow field of cerebrospinal fluid (CSF) in the brain [4]. Another application is the quantification of the deformation of soft tissues and elastic membranes of the human brain under the influence of the pulsatile CSF flow. We expect that our FSI model of the human brain will provide a significant

improvement in the understanding of diseases like hydrocephalus for which existing mathematical models are inadequate to describe large tissue displacements.

References

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