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Current and Future Trends in Computational Brain Injury Modeling

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Abstract

A concussion changes how the brain functions. Although everyone understands that brain injuries are dangerous, when engaging in sports, to many people head in-juries are acceptable risk. With estimated 2 to 4 million sports-related concussions a year, concussions are the most common type of sports-related brain injury. Current tests are not entirely dependable to identify concussion. There is no way to predict the time of recovery or who will suffer long-term symptoms. Similarly, current computational models are not entirely dependable either. Any computational model can be tuned to respond adequately to given loading conditions. However, in order to be used in real life applications it has been realistic, too. Although the brain and spinal cord are submerged in fluid, most models currently presented do not consider this important feature. Instead, they model the fluid using solid elements.

Keywords: Traumatic brain injury; Cerebrospinal fluid; Fluid-structure interaction analysis; Concussion

Introduction

A concussion happens when the brain is jarred hard enough to bounce against the skull. The cerebrospinal fluid (CSF) is to cushion the brain within the skull. Ultimately, it serve as a shock absorber. The CSF surrounds the brain as well as the central canal of the spinal cord. It lls the entire subarachnoid space and other cavities between the skull and brain. Other function of CSF is to circulate nutrients altered from the blood and remove waste products from the brain. After souring concussion, the most important step to take is to prevent further injury. However, the reported rate of concussion is smaller than the actual rate. Less than half of concussion cases in high school football players is reported. The most common reasons for concussion not being reported include a player not thinking the injury is serious enough to warrant medical attention (66.4% of unreported injuries), motivation not to be withheld from competition (41.0%), and lack of awareness of probable concussion (36.1%) [1]. Identifying and improving the awareness of the signs of concussion is therefore axiomatic. As McCrea et al. [1] state, Future prevention initiatives should focus on education to improve athlete awareness of the signs of concussion and potential risks of unreported injury"[1]. As described in the following Methods section, there are multiple computational techniques and models that can imitate the mechanism of traumatic brain injury (TBI).

Computational methods

Most head models reported in literature treat CSF as a solid part, as such; the CSF is incapable of owing around the brain when exposed to head trauma conditions [2-6] (Figure 1). The CSF flows even on its own when the head is at rest, albeit slowly. Naturally, when the head is exposed to a rapid deceleration, e.g. in a car accident, the CSF flows around the brain is expected to have a significant contribution to the head injury mechanism. Without the flows the simulated cushioning effect of CSF cannot be considered realistic. The reason fluid -structure interaction (FSI) methods are not usually considered, when simulating the mechanics of TBI, is their computational cost. A most recent model has combined smoothed-particle hydrodynamics (SPH) and high-order finite element methods to introduce a leap in TBI modeling that When the CSF fluid domain is replaced by solid finite elements, as it is com-mon with the older head models, the locations of the principal stress maximum values are more localized, as shown in Figure 2. When exposed to trauma e.g. to the frontal lobe, the flows of the fluid particles in the FSI model can be ob-served as they accelerate/decelerate between the frontal and occipital lobes providing cushioning effect to the brain. Consequently, the interaction between the brain gyriand sulci (i.e. folds and depressions in the brain that give the brain its wrinkled appearance) can be analyzed, but only when FSI analysis is used. In Figure 3 the SPH impulse intensity on the brain is superimposed with the Brodmann's map of cytoarchitectonics [7]. Brodmann has pioneered structural brain mapping, where he considered functional and pathological criteria for defining cortical areas in addition to cytoarchitecture. Figure 3 shows which functional areas are the most effected for given loading conditions, which, consequently, can be used to predict the concussion symptoms even before they appear. This is important because the symptoms of a concussion can be subtle and may not show up immediately e.g. to the frontal lobe, the flows of the fluid particles in the FSI model can be ob-served as they accelerate/ decelerate between the frontal and occipital lobes providing cushioning effect to the brain. Consequently, the interaction between the brain gyri and sulci (i.e. folds and depressions in the brain that give the brain its wrinkled appearance) can be analyzed, but only when FSI analysis is used.

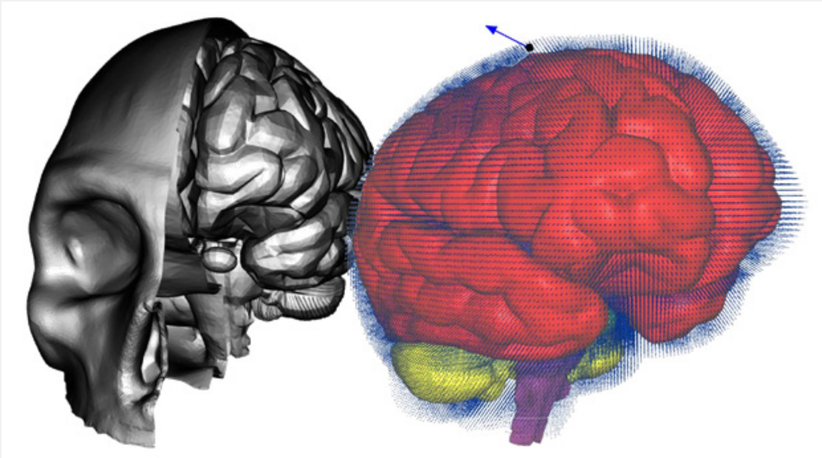

Figure 1: A detailed head model with skull, cerebrum, cerebellum, pituitary gland and brainstem. The subarachnoid space and other cavities are lled with uid SPH particles.

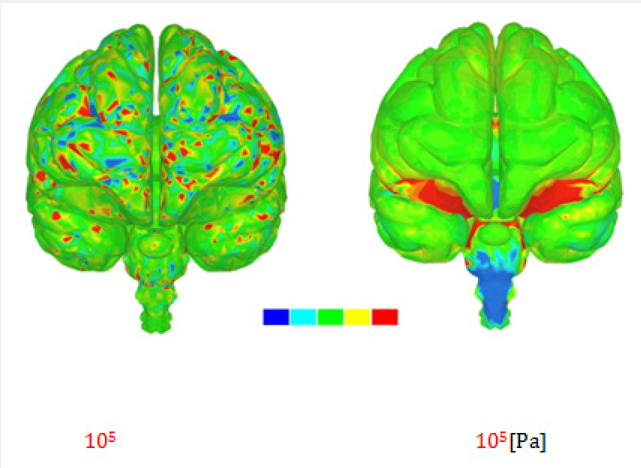

Figure 2: The second deviatoric principal stress obtained using (a) FSI analysis and (b) structural analysis.

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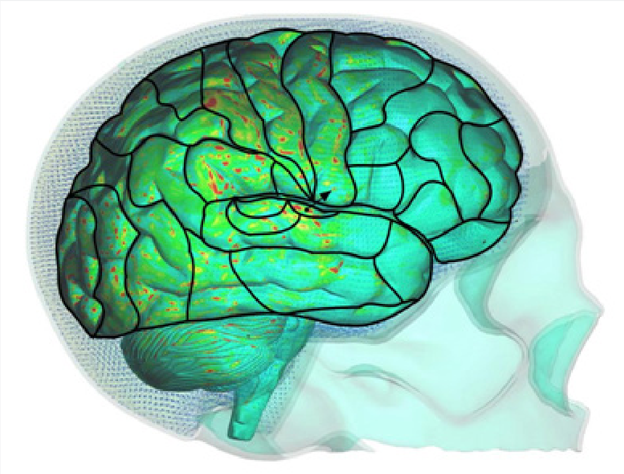

Figure 3: The SPH impulse intensity at the peak superimposed with the Brodmann's map of cytoarchitectonics.

Discussion and Future Trends

The interaction between CSF and brain gyri and sulci cannot be analyzed computationally if the methods used do not model the CSF as fluid. If the interaction of CSF with the brain is to be analyzed the CSF has to be modeled with fluid elements or particles and not just with fluid-like solid elements. The FSI results then have potential to show more complex responses to the loading conditions. An FS method, used to analyze the interaction between CSF and brain, is a step closer to understanding the mechanisms of traumatic brain injuries. The FSI analysis can predict the symptoms most likely to expect for given loading conditions. Hence, if used in practice, it can be used to contribute to early diagnosis which is important in concussion treatment. Moreover, when the model is realistic enough, a variety of loading conditions can be applied with and without personal protective equipment, e.g. helmets, to assess their effectiveness by comparison. Even though the FSI model is fairly advanced, it still lacks certain important features. However, the other models lack them as well. For example, the cerebral vasculature, which is omitted in these models, significantly alters brain stiffness. The network of arteries and veins creates a spring-like suspension system that restricts the brain motion [9]. The omission of cerebral vasculature is considered to be a major uncertainty in the currently proposed predictions. Moreover, in these models the displacement of CSF into the spinal subarachnoid space is also yet to be implemented. Natural CSF pulsation is too slow to affect brain dynamics in a head injury under high acceleration/deceleration [10]. However, due to the near incompressibility of the CSF, the displacement of CSF into the spinal subarachnoid space might occur at much higher wave speeds.

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