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On Application of Image-Based Finite Element Modeling in Injury Analysis

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Finite element modeling based on medical images is a new research field emerging in recent years, where the finite element model is constructed from medical images such as quantitative computed tomography (QCT) and magnetic resonance imaging (MRI). Image-based finite element modeling has many important applications in biomechanics and biomedical engineering [1-9], one of them is injury analysis. The objective of injury analysis is to predict injury risk and injury severity of human body under the effect of impact forces induced in various accidents. Reliable injury analysis is apremise for designing more effective protective devices such as car air-bag and sport helmet. Examples of injury analysis are: simulation of passenger collision in car crash, brain injury in sports, and osteoporotic fracture of the elderly due to fall.

Reliable injury analysis is very challenging to achieve due to the complexity in the human body and the complicated kinematic and kinetic conditions involved in various accidents. The human body has very complicated anatomical structures, which not only have disparate material properties but also span over very different spatial length scales. In addition, mechanistic causes involved in various injuries may also be diverse and complicated [10-15]. One example is head injury [16,17]. The human head has the most delicate anatomical structures. The central neural system including the tiny neurons and thin axons that resides in the soft brain tissues is the most important but also the most vulnerable one. The soft brain tissues and the central neural system are protected by the stiff skull, the meninges and the cerebrospinal fluid. Head injury is the most vital one among all the injuries. Head injuries can be classified into open and closed ones. Closed head injury such as concussion can be caused by a mild impact, where the skull is unbroken but the central neural system may have been severely damaged. It seems that closed head injury is not only determined by the magnitude of the impact force, but also by its direction, location, duration, and the unique anatomic structure of the human head. Helmets currently available in the market are quite effective in preventing open head injuries, but seem not equally effective for closed head injuries, as mechanistic causes of closed head injuries are different from those in open head injuries and they are not fully understood yet. To uncover mechanistic mechanisms resulting in closed head injuries, which are usually related to rupture of axons and dislocation of neurons, it is necessary to understand how the mechanical energy induced by impact is transmitted to and absorbed by the brain tissues at both macro- and micro-scopic level.

Conventional physical experiment methods, which mainly rely on dumbs and cadavers, have their limitations in studying injuries, as material and physiological conditions in dumbs and cadavers are different from those in *in vivo* human beings. Bio-fidelity of the physical model has been a major challenge in conducting experiments for investigating injuries. For example, intracranial pressure has a positive role in protecting the brain from mild impacts [18], but it is not maintained in cadavers. In addition to this, installation of sensors inside cadavers for collecting information such as tissue strains is either not practical or may significantly change the original conditions. Image-based finite element modeling has a number of advantages over the conventional experiment methods in studying injuries. In construction of an image-based finite element model, the required information such as geometry and material properties is extracted from medical images of the studied subject. Therefore, the obtained finite element model has much higher bio-fidelity [6]. Bio-fidelity of a finite element model includes geometric, material, kinematic and kinetic fidelity of the model to the original or realistic subject. Geometric bio-fidelity of finite element models used in injury studies has been greatly improved by using medical images [3]. Progress has also been made in improving the material bio-fidelity [4]. Finite element modeling is in principle able to provide any information inside the studied subject at any concerned locations. Finite element modeling is also very suitable and effective for conducting parametric studies, which would be very expensive and even impossible if conducted with physical experiments, andit is necessary to understand mechanistic mechanisms involved in various injuries.

However, challenges still exist in applying image-based finite element modeling in injury analysis [19]. For example, the quality of finite element meshes is one of the major concerns. The geometric models segmented from medical images are usually very complicated due to the complex anatomic structures of the human body. Distorted elements having poor shape quality is nearly inevitable in the generated finite element meshes, and low quality finite element meshes would produce unreliable finite element results [20]. Another example of the challenges is that kinematic and kinetic conditions of the subject involved in an accident are complex and they are usually very difficult to be retrieved from available on-site information. Therefore, the bio-fidelity of the loading, boundary and initial conditions applied in finite element modeling is difficult to be validated.

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