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Finite Element Analysis of Soccer Heading

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Abstract

Studies have shown compelling evidence that suggests heading soccer ball might lead to brain trauma. Researchers have attempted to experimentally quantify head acceleration induced by soccer ball heading. A series of linear accelerometers as well as angular accelerometer were used to measure head accelerations. This method however is limited to measuring only head acceleration during the impact. However, it is essential to analyse the acceleration of the brain in addition to the acceleration of the head that takes place during a soccer-heading manoeuvre. Since the motion of the brain is almost impossible to be quantified experimentally, this work focuses on performing finite element (FE) analysis of soccer heading to study the motions of both the head and the brain during the impact. FE model of soccer ball was developed and validated against published experimental data as well as a more detailed model. Moreover, FE model of human head that consists of the skull, facial bones, cerebrospinal fluid (CSF) layer and the brain was also developed and validated against experimental data of blunt impact on human cadaver. Both validated models were assembled to perform the soccer heading simulations. Linear and angular accelerations of the skull and the brain generated are comparable to those of experimental data. However, it has underestimated the angular acceleration due to the absence of neck in the model, but with comparable acceleration profile. Linear and angular accelerations of the brain were found to be almost similar to those of the head, which is contradictory to our initial hypothesis. Further study such as ball impact on instrumented dummy skull is required to corroborate the findings. Nonetheless, the FE models were able to replicate the head accelerations sustained during soccer ball heading satisfactorily. The simulation results show that the models can be employed in finding protective materials that can reduce the accelerations, thus minimising the probability of suffering from long-term brain trauma due to soccer ball heading.

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Keywords: Soccer heading; finite element analysis; head injury; brain injury; soccer ball model; head model.

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1. Introduction

Soccer is a unique sports, in which the purposeful use of the head to direct the ball in the game is allowed. There have been different opinions on whether heading soccer ball might lead to brain trauma. In the past decades, researchers have tried to quantify the impact of soccer heading through neuropsychological evaluations. This is a set of tests that measures the ability of one's brain to function properly. These studies have revealed that heading soccer ball contributes to cognitive dysfunction [1,2]. Moreover, the cognitive function of soccer players was also studied using a tablet-based approach. It was found that heading soccer ball might cause symptoms typically found in patients with mild traumatic brain injury (TBI) of the frontal lobes [3].

In addition, the brain of soccer players have also been evaluated by means of magnetic resonance imaging (MRI) technique known as diffusion tensor imaging (DTI). Both amateur [4] and professional soccer players [5] were examined using this method. These studies have found abnormalities in the brain of frequent headers similar to those found in patients with mild TBI. Furthermore, the former study on amateur soccer players has found compelling evidence that exceeding the threshold level of approximately 885 to 1,550 is associated with lower white matter fractional anisotropy (which indicates pathological changes in the brain tissue) and memory problems [4]. These findings suggest that heading soccer ball poses a long-term threat to the brain.

Studies have been conducted to experimentally quantify the impact of heading soccer ball. Linear and angular accelerations of the head were measured using accelerometers. The experiments were conducted on both human subjects as well as dummy headform [6–8]. Moreover, mathematical models were also employed to predict the head acceleration sustained during soccer ball heading [9,10]. All these methods were able to measure or predict the acceleration of the head as a single unit. However, the concern of possible brain injury is in fact associated with the acceleration of the brain. Thus, it is vital to know the amount of accelerations sustained by the brain during soccer heading in addition to head acceleration.

Measuring brain acceleration in vivo is almost impossible. Hence, finite element (FE) analysis is one of the promising methods that can be used to predict the brain responses due to soccer ball heading. FE analysis has been mostly used to study head injuries occurred in car accidents as well as those occurred in contact sports. However, to authors' knowledge, no FE analysis has been done to quantify brain accelerations endured during soccer ball heading. This study focuses on the development and validation of FE models of soccer ball and human head. Both validated models will be used to perform FE analysis of soccer heading. Head and brain accelerations are the parameters of interest that will be measured in the analysis. Head accelerations obtained from the simulation will be compared with experimental data from literature [7] to evaluate the reliability of the model. The following section describes the development of the required FE models as well as the analysis done. The subsequent section discusses the results obtained from the simulations.

2. Method

2.1. Finite element modelling of soccer ball

Soccer balls are normally made of 32 manually stitched composite panels that are pressurised through an internal latex bladder. However, to simplify the FE model of the ball, the model was developed using a hollow spherical shell that possesses isotropic material properties instead of modelling the 32 panels separately. The surface of the shell was discretised into 2,400 linear quadrilateral elements in Abaqus/CAE. The use of composite shell has greatly increased computational efficiency compared to three-dimensional continuum elements. The composite shell element includes two layers, namely an inner bladder that is 0.2 mm thick, and an outer panel that is 2.2 mm thick.

Tensile response for each layer was extracted from [11] and were applied to the model by fitting a hyperelastic reduced polynomial strain energy potential equation against the tensile test data. The reduced polynomial strain energy potential form is given by following equation:

$$U = \sum_{i=1}^{N} C_{i0}\left(\bar{I}_1 - 3\right)^{i} + \sum_{i=1}^{N} \frac{1}{D_i}\left(J^{el} - 1\right)^{2i} \qquad (1)$$