TOLERANCE LIMITS FOR MILD TRAUMATIC BRAIN INJURY DERIVED FROM NUMERICAL HEAD IMPACT REPLICATION

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INTRODUCTION

Human body mathematical modeling in impact biomechanics was firstly led in order to predict body kinematics and only later to define injury mechanisms. The objective of the undergoing research is to produce numerical tools which are able to predict head injuries. The present study focuses on the injury prediction capability of a numerical head model simulating professional football players who undergo significant head impacts resulting in minor traumatic brain injury.

KEYWORDS

Head Biomechanics, Accident reconstruction, Finite Element Method, Injury criteria, brain.

METHODOLOGY

Linear and angular head acceleration data obtained from a total of twenty two helmeted head impact reconstructions were employed in the evaluation of the numerical model response. The cases involve nine injured and thirteen non-injured players as detailed by Newman et al. (1999, 2000).

In the current study, the measured linear and rotational headform accelerations have been converted into velocity fields that were applied to a human head finite element (FE) model from Strasbourg University : the 'ULP' FEM of the human head. The main characteristics and material properties of that FEM are the following :

- a visco-elastic brain (density = 1040 kg/m3 – bulk modulus = 1.125 e+3 Mpa – short time shear modulus = 4.9 e-2 Mpa – long time shear modulus = 1.62 e-2 Mpa – decay constant = 145 s-1) in brick elements.
- an elastic CSF layer to reproduce the relative motion between the brain and the skull (density = 1040 kg/m3 – Young modulus = 0.12 e-1 Mpa – Poisson's ratio = 0.49) in brick elements;
- two elastic membranes : the falx and the tentorium (density = 1040 kg/m3 – Young modulus = 3.15 e+1 Mpa – Poisson's ratio = 0.45) in shell elements.

The skull properties are, in the present study, of no importance (except its inertia) since it is considered as a rigid body. The development and the complete description of this FE model was related by Willinger et al. (1999). Validation was conducted against experimental cadaver impact tests covering a large range of impact conditions. A general overview of that FE model with its own specificities is given in Figure 1. For this study, the skull of the model was considered as a rigid body for application of the velocity fields and the brain response was determined in the absence of skull deformations. This hypothesis should not affect model outputs given that only minor traumatic brain injuries with no skull fracture are taken into account in the present study relative to helmeted subjects. Similar assumptions were made during the experimental impact reconstructions where a dummy head with a scalp and rigid skull was used.

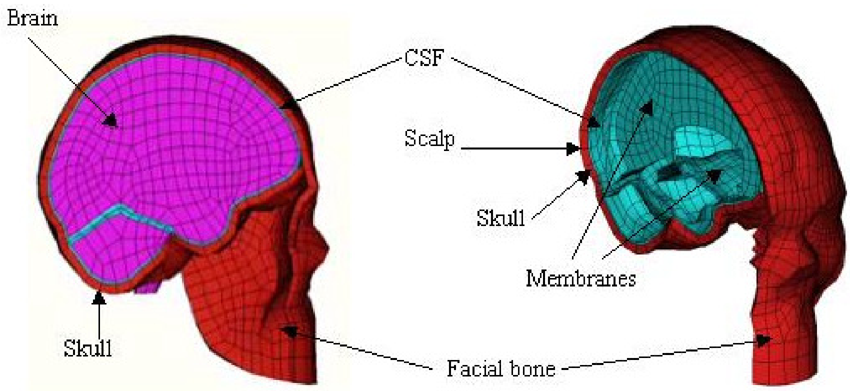

Figure 1 : Meshing of the intra-cranial medium

RESULTS AND DISCUSSION

During the numerical impact simulations, intra-cranial stress fields were calculated including shearing stresses expressed as the Von Mises criterion and normal stresses expressed as pressure. The maximum values of both shearing and normal stresses were then determined as well as the location where these maximum values were reached.

Variation in the intra-cranial pressure (between 50 kPa and 200 kPa) is not sensitive to whether or not the player are concussed. Figure 2 clearly illustrates that observations. The locations of the maximum pressure sustained by the brain are moreover variable and distributed all around and inside the brain tissue. Therefore intra-cranial pressure may not be an injury criteria for concussion when remaining under 200 kPa.

The Von Mises stress sustained by concussed players reaches values greater than 15 kPa, except for case 71-1 who sustained a Von Mises stress of 22 kPa without being concussed as shown in Figure 3. On the other hand uninjured players never exceed a 15 kPa Von Mises stress level in the brain. The maximum shearing stress levels are distributed at different parts of the brain according to the considered case. The above observations led to the conclusion that intra-cerebral Von Mises stress is a good indicator for concussion with an upper limit of approximately 15 kPa, wherever that intra-cerebral Von Mises stress occurs.

These results are consistent with the conclusions of an injury tolerance limit study on motorcyclists accidents published by Willinger et al. (2000). Nevertheless, in that past study, the critical Von Mises stress values for the brain resulting in concussion was estimated to be above 20 kPa, which is higher than the limit deduced from the present study. The value of 20 kPa may have been over-estimated since for the involved cases, either Von Mises stresses in the brain with values lower than 15 kPa were present for uninjured motorcyclists, or Von Mises stresses in the brain with values larger than 20 kPa were present for the concussed one's. The differences in injury severity, mild vs. severe head injury, is also rationale for the different tolerance levels proposed.

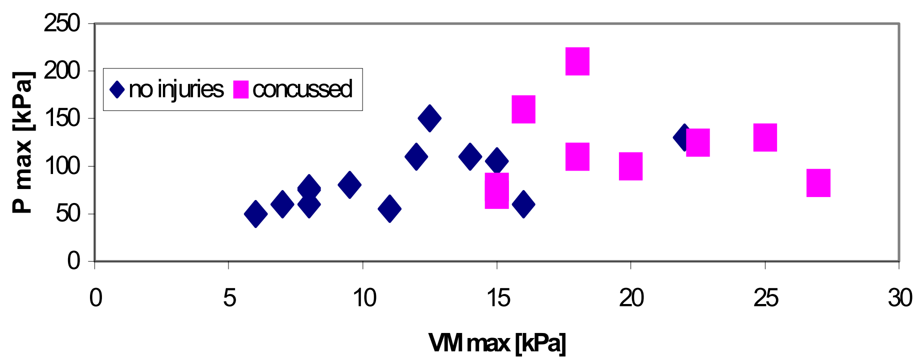

Figure 2 : Results of the 22 impact simulations showing the brain sustained maximum pressure vs Von Mises stress.

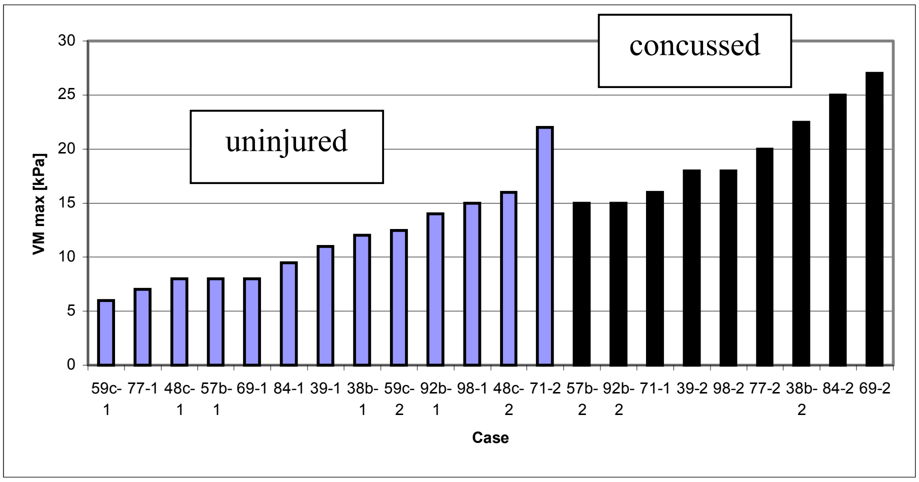

Figure 3 : Histogram of intra-cranial Von Mises stress relative to the 22 impact simulations of football players ; 13 uninjured followed by 9 concussed football players.

CONCLUSION

This study allows to propose first tolerance limits for mild traumatic brain injury derived from numerical head impact replication in terms of intra cerebral stress level. Thus, the current analysis led to the consideration of intra-cranial Von Mises stress as a good injury criteria for concussion or other mild traumatic brain injuries when reaching values above 15 kPa. This conclusion shows that the final target, which is to define a threshold value for a given head injury mechanism, can be reached. This can only be truly realized with an extended study involving a large number of accident cases of very different characteristics to define realistic head tolerance limits for specific injury mechanisms. It must also be kept in mind that the proposed stress levels are relative to a specific FE model and that comparative studies are needed in order to analyse other FE models responses under similar inputs.

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