On the Influence of the Morphological Variabilities of the Head on its Biomechanical Response: a Numerical Approach based on a Geometrical Parameterised Finite Element Model

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I. INTRODUCTION

Brain concussion is a common injury of the head in contact sport, but its physiopathology is not completely understood. The injury mechanisms of the brain are directly correlated to the applied boundary conditions, but the influence of morphological variability of the head has rarely been assessed. The goal of the present study is to design a geometrical parameterised finite element (FE) model of the head and its main inner components that will allow an investigation of the influence of geometry on brain injury risk. Presented here is a preliminary study, based on impacts from the literature, to show the potential of such a method.

II. METHODS

Parametric Finite Element Modelling

The method of parametric modelling employed was previously proposed in our laboratory [1-3] and was adapted for the head and its main components (cranial cavity, brain, ventricular system, *cerebellum*, brain stem, *falx cerebri*, *tentorium cerebelli*, ventricles, the main sinus and bridging veins). The coordinates of 12 anatomical landmarks and 162 geometrical primitives, requiring 383 parameters, were used to construct the whole mesh. Shell elements (≈2,700) were used to model the scalp, the skull, the *falx cerebri* and the *tentorium cerebelli*, while tetra elements (≈61,000) were used to mesh the brain volume, the blood in the main sinus and the cerebrospinal fluid (CSF) in the ventricles. The 11 pairs of bridging veins were also modelled with spring elements (Fig. 1). For this first study, mechanical behaviours of all the anatomical structures were modelled using homogeneous and linear elastic material laws; mechanical properties were extracted from the literature. In this first approach, a tied interface between the surface of the brain and the surface of the skull was used to model their interaction.

Influence of the geometry

The geometric variations of the skull anatomy were identified from a Principal Component Analysis (PCA), performed on a database of 40 intra-cranial surfaces reconstructed from CT-scan data (AP-HP, authorisation 1980120 - 9♀/31♂, mean age (± SD) = 60 ± 20.8 yo). From this PCA, the first six modes were extracted, accounting for 85% of the geometric variability in the database. Thirteen geometries were then constructed: a mean geometry (M) and, for each mode N, two models representing the geometric variations at plus (N+) or minus (N-) three standard deviations around the mean geometry. These geometries were then used to build 13 FE models using the method described above (Fig. 1). The internal structures were obtained from a non-linear deformation.

The frontal impact N°37 from the study of Nahum *et al.* [4] was simulated. Frontal, parietal and occipital pressures, as well as in the posterior fossa, were recorded [4]. The quality of the simulations was assessed by comparing the results obtained with the experimental results [4]. The influence of geometry was then evaluated by comparing the values obtained with the 13 models.

III. INITIAL FINDINGS

The Parametric Finite Element Modelling procedure worked for all 13 studied geometries (Fig. 1) and all the simulations were completed correctly. Figure 2 shows the maximum frontal pressure values measured for the 13 simulated models and their comparison with the experimental data [4].

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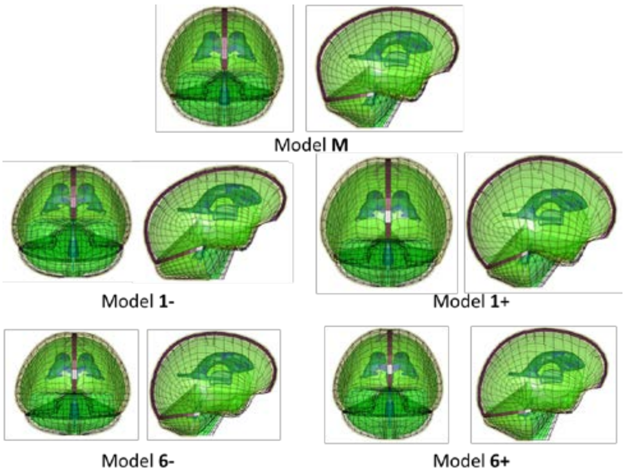

Fig. 1. Example of Finite Elements models obtained for the mean geometry (**M**), the mode 1 (**1-** and **1+**) and the mode 6 (**6-** and **6+**).

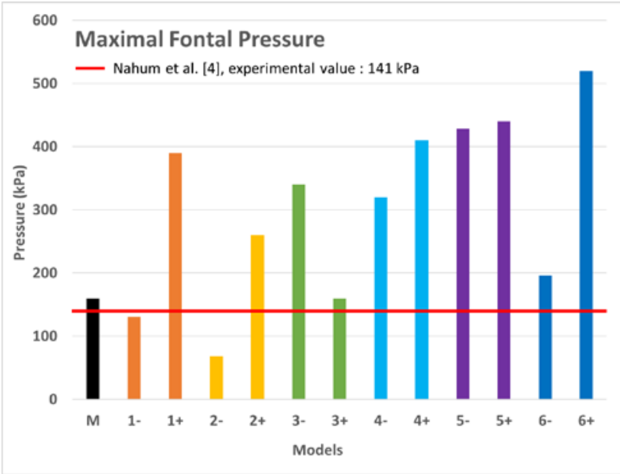

Fig. 2. Variation of the maximal frontal pressure (kPa) across models and comparison with experimental results [4].

The maximal pressures measured for each model are of the same order of magnitude as those measured experimentally [4]; however, it is observed that the pressures measured in the models in the posterior fossa and occipital lobe are always higher (absolute values) than the experimental value. The mean geometry (**M**) is always closest to the maximal reference pressures: frontal 159 kPa vs 141 kPa [4], parietal 62 kPa vs 73 kPa [4], occipital -83 kPa vs -48 kPa [4], and posterior -128 kPa vs -60 kPa [4].

The anatomical variabilities seemed to have an impact on the measured pressures. For example, Mode 1 (Fig. 1), which mainly describes a variation in the volume of the frontal, parietal and occipital parts of the skull, showed a huge influence on the pressures measured in these three zones. The comparison between models **1-** and **1+** showed increases of 200% for frontal pressure, 50% for occipital pressure and 40% for parietal pressure. Mode 6 (Fig. 1), which describes only a symmetrical change in the width of the cranial cavity, also modified pressures (comparison between **6-** and **6+**: frontal +165%, occipital -32%, parietal -26%), except in the posterior fossa (+3%). However, it is necessary to analyze these first results carefully since the geometric variabilities used are extreme (±3SD).

IV. DISCUSSION

The proposed parametric modelling allowed us to create FE models for different anatomies of the head and to perform an initial investigation of the influence of the geometry on its biomechanical behaviour. However, these results need to be analysed qualitatively because of the simplifying assumptions that have been made. First, the use of a tied interface limits the movement of the brain in relative to the cranial vault and thus "virtually" increases the shearing of grey matter. Another example is the couplings between the anisotropic and/or non-linear behaviour of some materials that could have a significant impact on the measured pressures. Other boundary conditions described in the literature must also be investigated to ensure the validity of these models. Finally, a more in-depth statistical study, coupled with this type of modelling, should make it possible to identify the anatomies that are most at risk.

V. REFERENCES

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