Skull Fracture Pattern Prediction Using a Parametric Skull Model for Children 0–3 years old

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I. INTRODUCTION

The head is one of the most frequently injured body regions for children [1], and skull fracture is the leading cause of paediatric fatality and disability in the USA [2]. Many attempts have been made to assess and predict paediatric head injuries using child anthropometric test devices (ATDs) and/or finite element (FE) models. However, these studies used paediatric head models at only a few fixed ages and morphologies, therefore they could not consider the effects of biomechanical variability on paediatric head impact response and injury prediction. In this study, we present a knowledge-based approach to better predict paediatric skull fracture pattern using a parametric head FE model.

II. METHODS

Fig. 1 shows the overall procedure to predict paediatric skull fracture. The proposed method consists of three steps: (1) obtain subject information, such as CT data and subject characteristics; (2) generate a subject-specific head FE model by morphing a baseline FE model, based on patient-specific landmark data, and a parametric head geometry model developed using principal component analysis (PCA) and multivariate linear regression; and (3) simulate the subject-specific FE model under the given impact conditions and material property, so that predictive injury curves can be obtained based on these simulations.

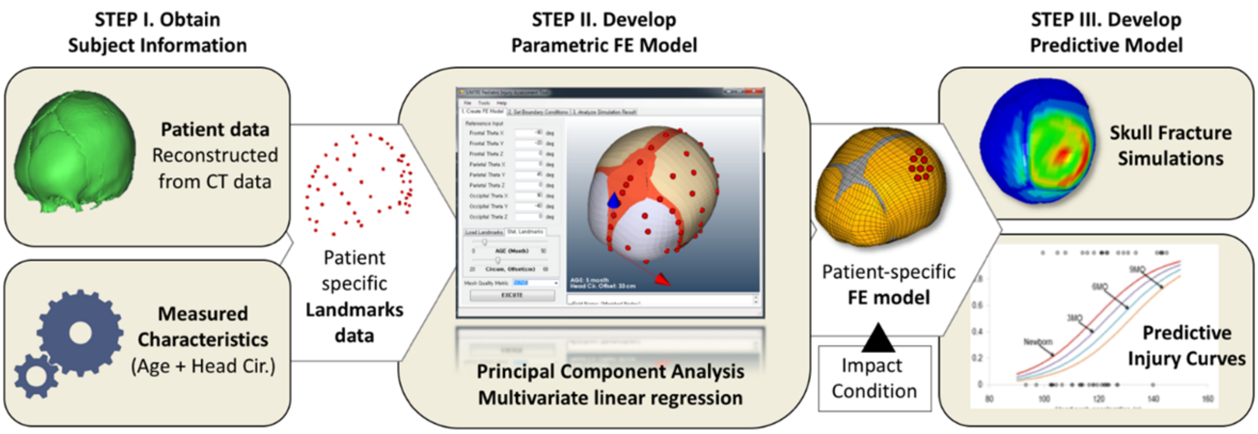

Fig. 1. Overall procedure of the proposed method to predict paediatric skull fracture using a parametric FE model.

CT data of 158 child subjects aged 0 to 3 years old (YO) were analysed to develop the parametric model using principal component analysis (PCA) and multivariate linear regression analysis. Prior to analysing the data, a set of landmarks was collected from CTs. The landmark data incorporate information about the skull thickness and the morphologies of skull surface and sutures. These data were then analysed using PCA, and a total of 20 principal components (PCs), which accounts for 99% of the data variance, were retained. Measured characteristics of the subjects, such as age and head circumference, were used as parameters to associate with the PCs using a multivariate linear regression analysis. Using this statistical model, a new set of landmarks can be predicted from any given set of parameters. We obtained the entire subject-specific model by morphing a baseline FE model based on the landmarks. Fig. 2 shows examples of the morphing results.

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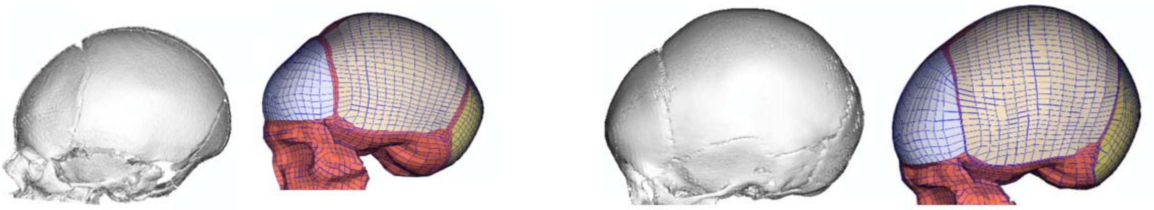

Fig. 2. Examples of target models reconstructed from CT data (*left sides*) and the predicted FE models from two predictors, such as age and head circumference (*right sides*).

In the current study, 50 actual child fall case data were collected by conducting in-depth site investigations to compile a reliable predictive injury curve. Computational fall reconstructions were conducted for 34 of the 50 cases through MADYMO simulations. With the given FE model, impact condition and material properties, we simulated three of the investigated head injury cases using LS-Dyna in order to predict the pattern of a fracture on the skull. Note that the material properties can be found in our previous works [3-4].

III. INITIAL FINDINGS

The predicted landmarks were compared with the actual data of the same subjects. Errors in X coordinates had a mean value of 0.07 mm with a standard deviation (SD) of 2.26, Y errors had a mean of 0.13 mm (SD 3.05), and Z errors had a mean of 0.93 mm (SD 4.06). From MADYMO simulations, it was found that in most cases the final impact velocity is not much affected by the initial condition as long as the fall height is controlled. The simulated FE results showed a good potential for injury pattern prediction compared to the actual fractures. Fig. 3 shows an example of simulated FE results using the proposed method, along with the actual fracture CT image.

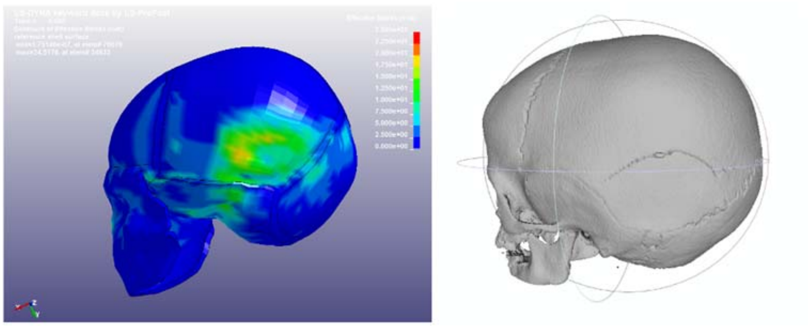

Fig. 3. An example of simulated Von-mises stress distribution (*left*) and the actual fracture image (*right*).

IV. DISCUSSION

We presented an approach to predict the skull fracture pattern of a specific child using a parametric paediatric FE model. The model allows for rapidly obtaining a good quality, subject-specific FE model with a few given parameters, so that a fracture pattern can be estimated under the given condition and material property. One of the major limitations is that the material properties of a specific paediatric skull cannot be easily determined due to lack of paediatric cadaver experimental data, which means the results can be varied according to change of material properties. However, the proposed approach still has a value in analysing the sensitivity of injury patterns to the skull geometry and impact conditions with the given material properties. The other limitation is that cortical bone thickness values in certain areas around the top of the skull measured relatively small due to the CT image resolution (1.25 mm between slices). To resolve this inherent problem with the resolution of typical clinical CT scans, we used an average value from the four closest landmarks for landmarks with the small values.

V. REFERENCES

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