Paediatric Head Injury Prediction: Investigation of Suture Material Properties

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I. INTRODUCTION

Head injury is the leading cause of paediatric fatality and disability, mostly resulted from motor-vehicle crashes, falls or physical abuse. One of the most common forms of head injury is skull fracture and it is often accompanied by brain injuries. To accurately assess paediatric head injuries, computational models need to have accurate geometry and material properties. Our previous studies have developed parametric paediatric head finite element (FE) models accounting for anatomical variations among 0-3 year-old children [1]. In this study, we focused on using those models to investigate the effects from suture material properties on paediatric head impact responses. Sutures are connective tissues that join the skull bones. These tissues are wider in infants that close completely before age three. Typically, simple linear elastic material was used for modelling suture tissues. However, some studies suggested that non-linear material is necessary for suture material modelling [2]. Therefore, the objective of this study was to investigate impact response differences between applying a non-linear material and a linear material for suture in infant head models. This study also served to validate the parametric infant head FE modelling methodology developed previously through subject-specific model validation.

II. METHODS

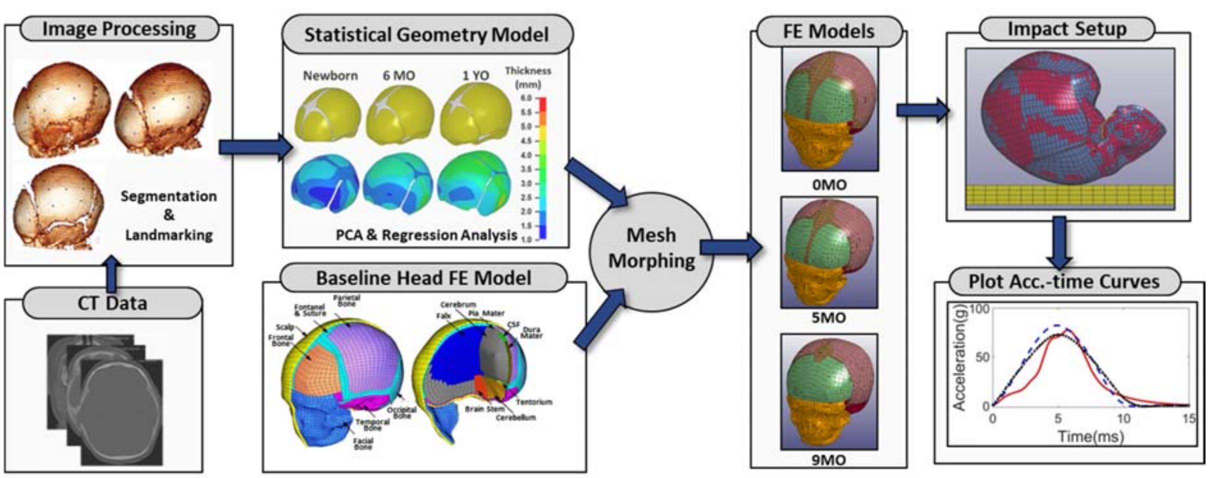
Experimental Testing

In this study, post-mortem human subject (PMHS) infant head drop tests with a drop height of 30 cm and head compression tests conducted by [3] were simulated. The experiments were performed using heads from a newborn, a five month old (MO) and a 9MO. The head length, width, and circumference for these specimens were reported. The head drop tests were conducted with five impact locations – forehead, right parietal, left parietal, vertex and occiput regions. Details regarding impact angles as well as acceleration time histories were reported. The force-deflection curves for anterior-posterior (AP) compression and left-right compression were also reported.

Computational Modelling

FE head models corresponding to the size and age of the specimens in the experiments were developed by morphing a baseline 6MO head FE model into statistically predicted head geometry based on CT scans of 56 0-3 year-old children [1] . FE simulations were set up based on the impact angle and velocity defined in the tests. Model-predicted acceleration histories and force-deflection curves were compared to the experimental results. The process for subject-specific model validation is shown in Figure 1.

FIG. 1. PROCESS FOR SUBJECT-SPECIFIC MODEL VALIDATION



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Material Modelling

All linear material properties of the head were based on the study conducted by [4]. Simulations were conducted with skull Young's Modulus (E) as a covariate with values of 164.3MPa (determined by matching previous newborn PMHS test data), 400MPa and 500MPa. Linear and non-linear material parameters of the suture are given in Table I based on the literature.

TABLE I
LINEAR AND NON-LINEAR SUTURE MATERIAL MODELLING

Parameters	Young's Modulus (MPa)	Poisson's Ratio	Density (kg/m³)	References
Linear Suture	15.8	0.49	1130	[4]
Non-Linear Suture	$Nominal\ Stress = \mu_1(\lambda^{-1+\alpha} - \lambda^{-1-\frac{\alpha_1}{2}})$ $\mu_1 = 0.0148, \alpha_1 = 6.9, \lambda = Stretch$	0.499	1133	[2]

III. INITIAL FINDINGS

FIG.2. COMPARISON OF ACCELERATION-TIME CURVES AND FORCE DEFLECTION CURVES

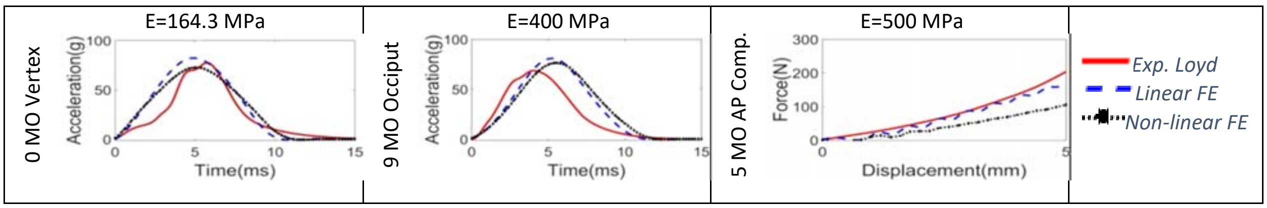

TABLE II
SUMMARY OF CORRELATION SCORE

Age		0-Month-Old				5-Month-Old				9-Month-Old			
Skulls Young's Modulus (MPa)		164.3	400	500	Average	164.3	400	500	Average	164.3	400	500	Average
Suture Material	*Linear: CORA*	0.67	0.56	0.57	0.60	0.61	0.72	0.84	0.73	0.70	0.76	0.70	0.72
	Non-Linear: CORA	0.67	0.55	0.56	0.59	0.61	0.68	0.76	0.68	0.68	0.73	0.74	0.72

IV. DISCUSSION

Figure 2 shows exemplar model-predicted acceleration-time and force-deflection curves with both linear and non-linear material models against the experimental results for different impact locations. The corresponding correlations were given by the CORrelation and Analysis (CORA) rating shown in Table II. Based on the individual and average CORA scores, the usage of non-linear material for the suture is not explicitly beneficial. Student's T-test conducted between linear and non-linear models resulted in a p-value of 0.59, indicating that it was *no*t statistically significant. Lower peak acceleration values were always associated with non-linear suture property, indicating that the whole head structure is made softer by the non-linear model than the linear model. However, the non-linear model did not provide a significantly better match to the test results than the linear model. On the other hand, the Young's Modulus of the skull showed more sensitive effects than the suture material. The average CORA values for the 5MO and the 9MO were significantly higher with higher skull Young's Modulus. For the 0MO a higher skull Young's Modulus drastically reduced the correlation. It indicates that there is a potential trend that increasing age is associated with higher skull modulus, which can be correlated with the increase in stiffness of skull with progressing age. However, this trend cannot be confirmed due to the limited number of subjects and requires further research. Regardless of the suture and skull material properties, the comparison between the test and simulation results showed the parametric FE infant head modelling technique developed previously to be fairly accurate. A limitation associated with the study is about parietal impacts, in which a plateau region in the acceleration histories cannot be replicated in the simulations. To further validate the model, PMHS measurements at tissue-level deformation may be needed.

V. REFERENCES

[1] Li et al, PLOS ONE, 2015
[2] Li et al, Biomech and modeling, 2017
[3] Loyd et al, Diss. Duke University, 2011
[4] Li et al, Journal of Legal Medicine,2015