Development of a Statistical Shape Model of the Infant Femur

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Background: Little is known about the fracture potential of pediatric femurs due to the scarcity of pediatric tissue specimens. A statistical shape model could provide a means of generating representative pediatric femur models for biomechanical evaluation when other methods are not possible. The objective of this study was to develop a statistical shape model of the infant femur where anthropometric features act as inputs to the model for future generation of representative femur models for children of various ages.

Methods: CT scans of 42 infant decedents (0-11 months old) were obtained from the University of New Mexico Radiology-Pathology Center for Forensic Imaging. The left femur was segmented for each subject. To have a similar and aligned mesh for each femur, anatomical landmarks were identified, and a baseline mesh was created. The baseline mesh was morphed to each of the remaining femurs using RBFmorph (Monte Compatri, Rome – Italy) which optimizes the use of radial basis functions to complete the morphing.

MATLAB was used to conduct a principal component analysis on the nodal coordinate data of the morphed meshed models. Three outliers were identified and excluded using the Hotelling T^2 statistic ($\alpha = 0.05$). Six femur models (one from each 2-month bin) were then reserved to evaluate the predictive ability of the model. A partial least squares (PLS) regression was used to regress the anthropometric features (age, height, weight, and body mass index) with the principal component scores.

Results: The first two principal components, accounting for 99.95% variance of the training set, were found to be significant in the PLS regression with age and height as the predictors. The overall test set resulted in $R^2=0.53$ with a root mean square error of 5.9mm where only two had greater than 2mm mean nodal reconstruction error (Figure 1). When normalized to femur length, the mean and max nodal reconstruction error was 0.67%-6.02% and 2.03%-9.33%, respectively. Reconstruction errors were found to be greatest at the lesser trochanter, the intertrochanteric crest, and the distal aspects of the distal condyles (Figure 2).

Discussion: A statistical shape model of the infant femur was developed. Newly generated femur models can be used in finite element analysis to study biomechanics and fracture potential. Compared to adult femur statistical shape models, our model captured more of the variance of the training set with fewer principal components, but the R^2 was lower suggesting a lower predictive ability (Klein, 2015). This result is likely due to the greater variation of morphology changes with age for infants in addition to a limited sample size used to develop the model. A limitation of the developed model is that both principal component analysis and PLS regression only consider linear relationships; non-linear relationships may improve the predictive capability. Future work will aim to improve the model's predictive capability and expand the included age range. An additional 57 pediatric femur CTs (12-35 months old) are available for inclusion in the model. Additional anthropometric features such as sex and race will also be considered.

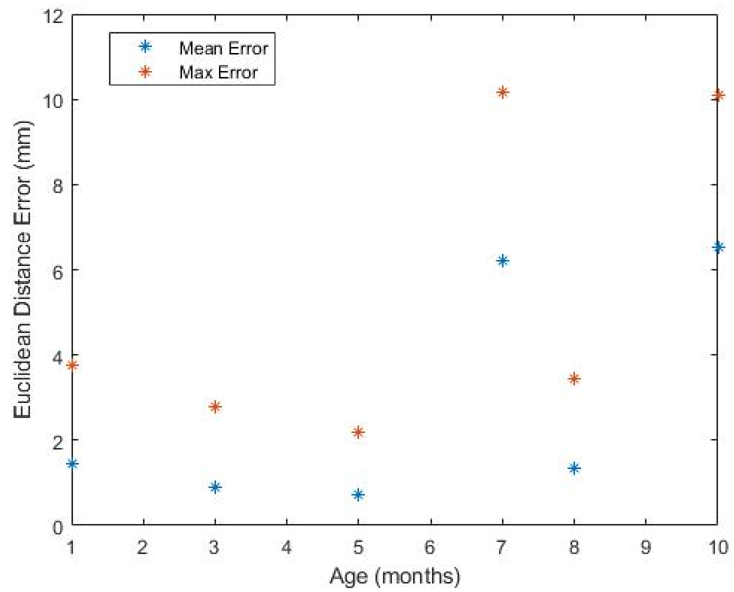

Figure 1. The mean and maximum nodal reconstruction error of the test set by subject age.

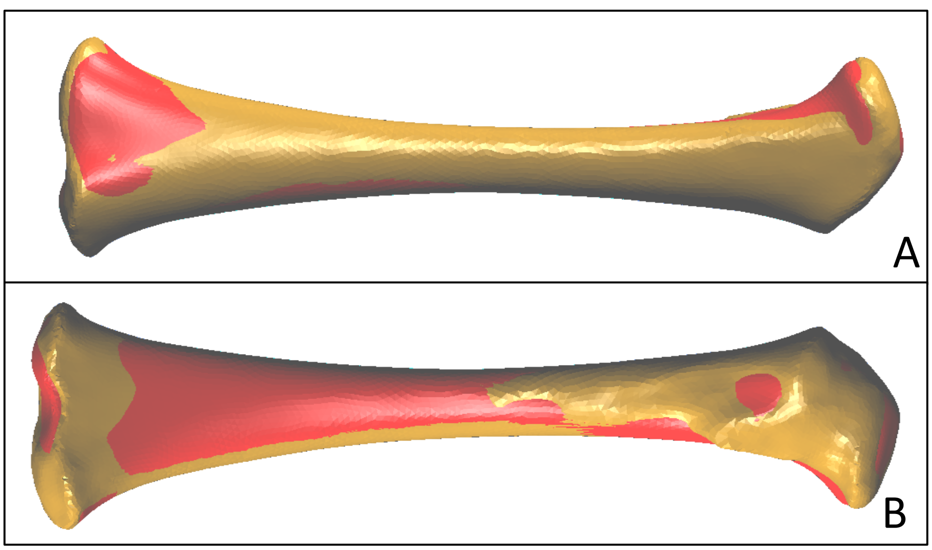

Figure 2. Anterior (A) and posterior (B) views of the actual (brown) and reconstructed (red) 1-month old femur of the test subset.

References

Klein, K. F., Hu, J., Reed, M. P., Hoff, C. N., & Rupp, J. D. (2015). Development and Validation of Statistical Models of Femur Geometry for Use with Parametric Finite Element Models. Annals of Biomedical Engineering, 43(10), 2503–2514.