Development of femoral and tibial statistical shape and density models for personalized pediatrics FE models

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Summary

We developed statistical shape-density models that capture bone morphology and bone mineral density variations of the femur and tibia in a pediatric population aged 4 to 18 years. We found an average geometric prediction error of less than 2mm and a normalized prediction density error ranging from 7.9% to 13.5% across various regions of interest which highlighted the models' robustness and reliability in reflecting real-world physiological variations in pediatrics' femora and tibiae.

Introduction

Children are not small adults and computational models using adult generic bone geometry and material properties do not represent children's bone shape and bone mineral density (BMD) [1]. To address this, we created a statistical shape and density model (SSDM) of the femur and the tibia for a pediatric population aged from 4 to 18 years old.

Methods

CT scans of 330 children (136 F, 12 ± 5 years., 148 ± 24cm tall, 49 ± 22kg) were acquired from the Victorian Institute of Forensic Medicine (Melbourne, Australia). Femora (657) and tibiae (652) were manually segmented, fitted to a surface template mesh, and morphed to a volumetric template mesh [2]. BMD was estimated from Hounsfield Units using a calibration phantom and assigned to each node using *Bonemat* [3]. Principal Component Analysis was performed to build two statistical shape and density models, one for the femur and one for the tibia, by using nodal coordinate and nodal BMD. For each SSDM, principal component (PC) weights were used to train a Partial Least Square Regression along with participants demographics and bone measurements (epicondylar width and bone length for the femur and tibial plateau width, malleolar width and tibia length for the tibia) in a leave one out (LOO) analysis. Root Mean Square Error (RMSE) between CT-based and predicted geometry were computed to understand surface prediction errors. Normalized RMSE (NRMSE) was calculated between CT-derived and SSDM-predicted BMD to estimate prediction error for each node and in each bone region.

Results and Discussion

Over 90% of the shape and density variation was captured using 29 PCs for the femur and 27 PCs for the tibia. The first PC in the tibia (from -2SD to +2SD) showed the shaft geometry (at the 25% bone length) going from circular to triangular shape in the anterior part associated with large variation in density (figure 1). From the LOO analysis, the average bone geometry prediction RMSE was 1.78 ± 0.46 mm in the femur and 1.41 ± 0.39 mm in the tibia. Regional NRMSE were lower in the tibia than femur (Table 1).

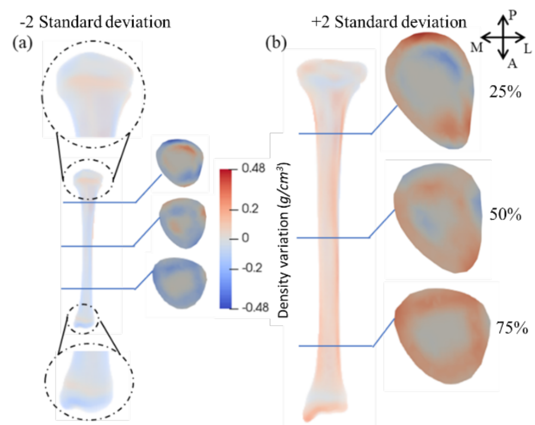

Figure 1: Anterior tibia view of -2SD (a) and +2SD (b) showing shape and BMD variation in the first PC for the tibia.

Conclusions

These statistical models have the potential for clinical application in rapidly generating personalized computational models without imaging data. Future work will look at improving prediction using partial medical imaging.

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References

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Table 1: Average BMD prediction error (NRMSE%) between the CT-derived and the SSDM predicted for each bone region and for each node.

	Femur						**Tibia**			
Region	Head	Neck	Trochanter	shaft	epiphysis	Node to node	Proximal	Shaft	Distal	Node to node
NRMSE (%)	13.5	12.9	13.2	8.9	12.9	26.7	11.5	7.9	10.5	28.7