Generation of 3D Pediatric Femur Models from 2D Radiographs

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Introduction
Evaluation of femur fracture risk, typically done using finite element (FE) models developed from computed tomography (CT) images, is currently limited in infants and toddlers as 2D radiographs are more common than CT scans given radiation concerns. Techniques for developing 3D models from radiographs have been developed for adults but applications in young children have been unexplored and are questionable due to the rapidly changing femur morphology in this population. Our objective was to evaluate methods to generate 3D models from 2D radiographs for suitability in pediatric femurs (aged 10-24 months).

Methodology
CT scans and 2D radiographs of the femur from 27 decedents aged 10-24 months were used. 3D models were previously developed from these CT scans. For each subject, a 2D femur contour was obtained from the anterior-posterior (AP) radiograph which is described by 60 points capturing important anatomical landmarks and equidistant locations between them. 4 femurs were reserved to form the test set.

Surface Generation. Two methods for generation of the outer surface of the femur were evaluated. The first method uses a partial least squares regression (PLSR) predicting the 3D femur shape using 2D femur length, subject age, height, and femur contour points. The second method, SSM+TPS, utilizes a previously developed statistical shape model (SSM) and thin plate spline (TPS) morphing to better conform an approximated SSM-derived shape to that of the radiograph. For each femur in the test set, the original CT-derived 3D femur model was compared to the predicted surface geometry. The percent difference in volume and surface errors and the mean and max nodal reconstruction errors were compared for the 2 surface generation methods. Metrics computed for the overall test set were the root mean square error (RMSE) and $R^2$.

Medullary Canal Generation. A PLSR was developed using the cross-sectional widths of the outer surface of the femur at 3 discrete cross-sections along the diaphysis with age and femur length as inputs to predict the medial-lateral (ML) and AP medullary canal widths at the corresponding cross sections. The overall RMSE for predicting the canal widths was calculated for each femur in the test set.

Results
Overall, the PLSR method yielded a more accurate model than the SSM method. The overall RMSE for predicting the medullary canal widths for each femur in both the AP and ML directions ranged from 0.44mm to 0.93mm. An example of predicting the canal for a femur from the test set is shown.

Conclusions
The PLSR method proved more suitable than SSM+TPS to generate the 3D surface model of the femur using 2D imaging. Future work will include FE analysis of the CT-derived 3D model and the combined predicted surface and medullary canal model where diaphyseal stresses and strains will be compared. The selected methodology will then be used to generate 3D models for children with abnormal femur morphology where only radiographs are available.