Prediction of the Structural Response of the Femoral Shaft under Dynamic Bending Loading using Geometric Subject-Specific Finite Element Models

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Abstract

Biomechanical response corridors from Post-Mortem Human Subject (PMHS) are used as the target responses for assessing biofidelity of anthropomorphic test devices (ATDs) and computational models. As the responses from biomechanical test data usually have large variance due to the anthropometric differences and physical characteristics, the first step in developing the biomechanical response corridors is to normalize subject responses to a standard size subject using scaling techniques. However, traditional scaling methods are limited in their ability to capture the effect of all geometric differences that may affect structural responses.

With contemporary development of computational modeling and imaging technology, subject-specific finite element (SS-FE) models have been increasingly employed in biomechanics field. Since the SS-FE models incorporate detailed skeletal geometry of specimens, they have the potential to predict the response of each specimen by capturing all aspects of geometric variability. If accurate subject-specific modeling techniques can be developed and validated, this may facilitate the development of parametric statistical FE models that can capture effects of anthropometric differences throughout the population. Among other applications, these could be used to develop biomechanical response corridors whose range of variability is informed by the statistical model responses.

The goal of this study was to predict structural responses of the femur under dynamic bending loading using the geometric SS-FE models, and to evaluate the prediction accuracy of the models, compared to that of various conventional techniques. Dynamic three-point bending tests of bare femurs (described by Forman et al. 2012) were simulated. The distal and proximal ends of the femur specimens were potted into cups, and the mid-span of the specimens were loaded in latero-medial direction by an impactor at 1.5 m/s. In total, tests performed on fifteen specimens were simulated in this study.

Geometric SS-FE models of the fifteen femur specimens were developed using a morphing technique. These were developed from a template femur FE model based on the geometry of the Global Human Body Model Consortium-owned GHBMC M50 Seated Occupant Model Geometries of the specimens were reconstructed from computed tomography (CT) data by

segmentation using thresholding method. Given the template FE model and the reconstructed subject geometry, control points for morphing were programmatically selected using an in-house MATLAB script focusing on the inner and outer surface shape of the femoral shaft. Morphing was conducted using a thin-plate spline with radial basis function.

Using the developed geometric SS-FE models, FE simulations were conducted under the same loading condition as the tests. To evaluate current scaling techniques, the response of each geometric SS-FE model was scaled to the others using the mass-based scaling and structure based scaling techniques. The impact force time history was used as the reference curve for the comparison, and the root mean square (RMS) error between scaled responses, model responses, and tests were calculated to quantify the prediction error.

The geometric SS-FE model captured the response variations of the PMHS better than the scaling techniques; scaling techniques even increased the prediction error at times. This result suggests a benefit of using geometric SS-FE models to capture the response variance shown from anthropometric variability compared to current scaling techniques.