Development, Validation, and Application of a Parametric Finite Element Femur Model

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ABSTRACT

Older, obese, and female occupants have higher risk of serious lower-extremity injuries in frontal crashes. Optimizing vehicle restraints to better protect these vulnerable populations requires finite element (FE) models of the human body that consider the variations in skeletal geometry, body size, body shape, posture, and material properties among the population. This paper describes the development, validation, and application of a parametric femur FE model as an example of these methods for an entire lower-extremity FE model. Bone geometries were extracted from CT scans from 98 subjects. A landmark-based mesh morphing and projecting process was used to fit a template mesh to the femur geometry from each subject. Thicknesses of cortical bone at each node of the template mesh were programmatically determined. The nodal coordinates and the cortical bone thicknesses of the fitted meshes were analyzed using principal component analysis and regression analysis to develop a statistical model of the femur that predicts femur nodal coordinate locations representing the bone surface geometry as well as the associated cortical thickness as functions of age, BMI, and femur length. The parametric FE model was validated by running 13 subject-specific simulations and comparing measured results from a study of femur PMHS tests in combined 3-point bending and compression loading conditions to predicted results. The validated FE model was then used to investigate the effects of occupant characteristics on femur response values. The statistical model showed good fit to PMHS femur geometries, and the FE model was able to match the subject-specific test results. The average error in the force curve results for the combined loading tests was about 1%. In the initial application loading condition, an increase in BMI caused an increase in peak force, while an increase in age caused a small decrease in peak force.