A Parametric Ribcage Model Accounting for Morphological Variations Related to Age, Height, BMI and Gender

Yulong Wang[1, 2], Zhonghao Bai[1], Libo Cao[1], Matthew P. Reed[2], and Jingwen Hu[2]

[1] State Key Laboratory of Advanced Design and Manufacturing for Vehicle Body, Hunan University, Changsha, Hunan, China
[2] University of Michigan Transportation Research Institute, Ann Arbor, MI, USA

Abstract

Objective: *Field data analyses have shown that the risks of thoracic injuries are significantly affected by occupant characteristics, such as age, gender, height, and body mass index (BMI). The objective of this study is to develop a parametric ribcage model that can account for the age, height, BMI and gender effects on ribcage morphology.*

Problem to be solved: *the current human body models generally only represent single ribcage geometry, and do not consider morphological variations that could potentially affect the thoracic injury risks.*

Methods: *CT scans from 45 subjects across both genders and a large range of age were obtained in this study. The ribcage geometry for each subject was collected through a series of image processing and numerical analyses, including threshold-based image segmentation, landmark identification on each rib, sternum and spine, and landmark re-processing through cubic spline and symmetry adjustment. After landmarks were identified, a template finite element (FE) model (THUMS 4 mid-size male model) was morphed into the geometry for each subject using a 3D interpolation and smoothing method based on Radial Basis Function with Thin Plate Spline (RBF-TPS). Generalized Procrustes Alignment (GPA), principal component analysis (PCA), and regression analysis were then used to develop a statistical model that use age, gender, height, and BMI to predict nodal locations for the THUMS mesh. Two regression models were developed, a quadratic model for quantifying the size variation and a linear model for quantifying the shape variation.*

Data to be included: *A total of 1036 landmarks were identified on the ribcage of each subject. The first 35 principal components (PCs) were selected to develop the regression model, which accounted 99% variance of the shape matrix. The first PC, dominated by the size effect, was significantly affected by the height (p=0.000), BMI (p=0.004) and age (p=0.007). Age (p=0.003), gender (p=0.000) and BMI (p=0.000) had significant effects on the second PC. Geometry validation shows that the model predicted reasonable size, shape, and cross-sectional area of the ribs, and the morphed FE mesh sustained comparable quality as those from the baseline model.*

Discussion and Conclusion: *This study developed a parametric ribcage model accounting for morphological variations relative to the age, gender, BMI and height. The ribs angle predicted by the model developed in this study showed a steady increase with the increase of the age, height and BMI with coefficients of 0.06°/year, 0.145°/cm and 0.572°/ (kg/m*^{2}*), respectively, which is similar to the trends reported by previous studies. The model also demonstrated an increase in kyphosis from young adults to elderly. Because a template FE mesh was used in the process of model development, the regression model can rapidly generate a subject-specific ribcage FE mesh with the input of age, gender, height and BMI. Simulation analysis based on the predicted models should be conducted to study the effect of the morphological changes on thoracic injuries in the future.*