Development of Age and Sex-Specific Thorax Finite Element Models

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Abstract

In motor vehicle crashes (MVCs), thoracic injury ranks second only to head injury in terms of the number of fatalities and serious injuries, the body region most often injured, and the overall economic cost [1,2]. The shape, size, bone density, and cortical thickness of the thoracic skeleton vary significantly with age and sex. Computational modeling has emerged as a powerful and versatile tool to assess injury risk and improve the effectiveness of vehicle safety systems. However, current computational models only represent certain ages and sexes in the population. The purpose of this study was to morph an existing finite element (FE) model of the thorax using thin-plate spline interpolation to accurately depict thorax morphology for males and females of ages 0-100. The thin-plate spline is a smooth function that interpolates the connections between the nodes while minimizing the amount of change in landmark positions. An approach based on Stayton was modified for the purpose of morphing a reference FE mesh of the thorax to create age and sex-specific thoracic FE models [3]. In order to execute the thin-plate spline interpolation, homologous landmarks on the reference, target, and FE model are required. Homologous landmarks were previously collected using the Generalized Procrustes Analysis to create functions describing the size and shape changes and shape changes in the ribs and sternum for males and females of ages 0-100 [4]. These functions quantified the target geometry by defining the locations of homologous rib and sternum landmarks for every age and sex. The Global Human Body Models Consortium (GHMBC) thorax model was used as the reference mesh and the ribs, sternum, costal cartilage, intercostal muscles, spine, and simplified thoracic cavity were morphed accordingly based on the homologous landmark data for the ribs and sternum. A total of 416 models were generated representing size and shape changes and shape changes of males and females for the following ages: 0 month, 3 month, 6 month, 9 month, and 1-100 years in one year increments. The GHBMC atlas mesh consisted of 134,051 nodes and 115,291 elements. In order to reduce computational time of the morphing process and improve mesh quality, a uniform 5% subsample of the landmarks from the reference and target were selected resulting in a reduction to 9,524 landmarks. The element quality of the reference and morphed FE models was analyzed by comparing the Jacobian test (>0.3), warpage test (<50°), and aspect ratio test (<8) results. The biomechanical response of an average individual of a given age and sex was studied through simulations of various frontal and lateral impacts using hub loading and seatbelt loading. The development of these age and sex-specific FE models of the thorax will lead to an improved understanding of the complex relationship between thoracic geometry, age, sex, and injury risk.

References

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