Human Body Model Thorax Morphing Method Based on Internal Landmarks Demonstrated with the Development of an Average 75-Year-Old Small Stature Female Model.

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I. INTRODUCTION

Modern Human Body Models (HBMs) can be repostured and morphed to study the biomechanical response of vulnerable anthropometric and age groups (e.g. aged population and small stature female) in a car crash. It has been shown that the rib position and shape vary between age groups [1] and can influence the biomechanical response [2]. Several methods to morph HBMs exist, for example outer surface target methods have been used to study the response of obese occupants [3], and internal landmark-based methods have been used to study the effect of various postures [4] in a car crash. In this study, a publicly available tool (PIPER) [5] was enhanced to allow for the morphing of the thorax in detailed HBMs. The proposed method enabled modification of the rib shape and orientation, in addition to the already existing ability to reposture the spine based on literature data [6]. The thorax target geometry was defined as a 75-year-old average small stature female ($F05_{75YO}$) based on regression models [1][7-8]. The morphed full-body model was evaluated using a side-impact sled simulation to assess model stability and response.

II. METHODS

In this study, the thorax of the GHBMC small stature female (GHBMC F05-O v5.1) full-body model ($F05_{24YO}$) was morphed to represent an average 75-year-old subject thorax ($F05_{75YO}$). The thoracic curvature, rib shape and rib orientation were modified based on literature data [1][8], while the neck curvature was modified to account for the thoracic curvature change so that the head was in the reported neutral position. The PIPER package (PIPER v1.1.0) and the GHBM F05-O v5.1 model metadata [9] were augmented (Fig. 1b and 1c) to allow for internal morphing of the ribs based on the length, twist, curvature, and orientation reported in the literature [1]. A CAD package (CATIA V5, Dassault systems, France) was used to convert the literature data [1][7-8] to PIPER targets. The target coordinates of the landmarks defining the rib shape were calculated by aligning the landmarks to the literature data in a CAD environment (Fig 1c). The PIPER simulation was performed in the 'Pre-Position' module and followed by three operations to achieve high mesh quality in the 'Smooth' module. First, the 'Kriging in a box' tool was used, selecting the whole model inside the box, then the "moving average" tool was used, followed by another 'Kriging in a box' operation [10]. The mesh of the newly developed model was assessed using a commercial post-processing tool (Hypermesh 10.0, Altair Engineering, Inc., Troy, MI) using the element quality criteria of commercial HBM (e.g. warpage < 50°, aspect ratio < 8, skew < 70° and Jacobian > 0.4). The model was then positioned and settled in a NHTSA configuration [11] side-impact sled model with an initial velocity of 6.6 m/s to assess model robustness. The simulated time includes the loading and unloading phase of the thorax. The thorax lateral compression at the 6th rib and the number of ribs exhibiting fracture were compared between the young and aged models.

a) General morphing metadata | b) Thorax morphing metadata – PIPER databased augmented | c) Three landmarks per rib segment

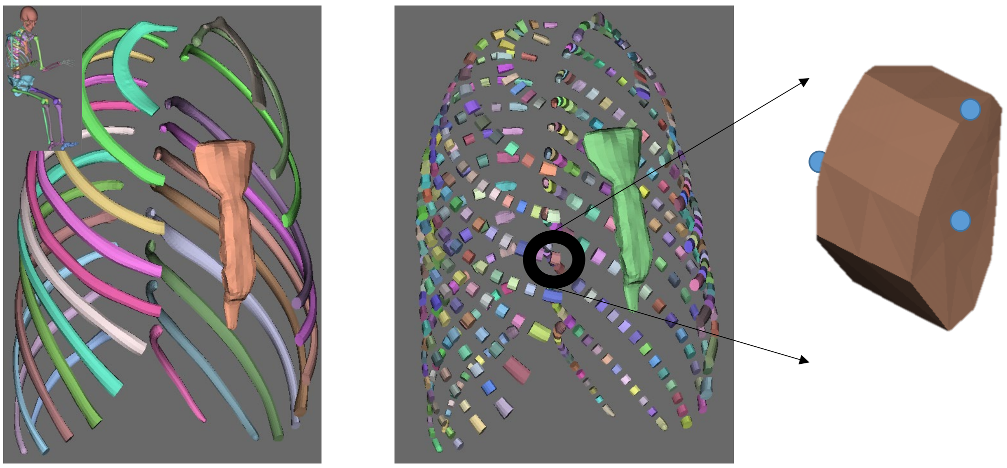

Fig. 1. a) PIPER metadata for full-body repositioning; b) PIPER enhanced metadata developed to morph the rib cage; and c) extended database including rib segments and corresponding landmarks.

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III. INITIAL FINDINGS

The aged F05 model met the target geometry within 0.05 mm measured at the rib centroids. The morphed ribs, intercostal cartilage and costal cartilage met the mesh quality requirements. For the soft tissues, 0.28% of the lung elements and the flesh adjacent to the scapula had a negative Jacobian and required manual intervention. After the mesh smoothing operations in PIPER and small manual intervention, the mesh quality of the $F05_{75YO}$ model was found to meet or exceed the mesh quality thresholds of the commercial models at the full-body level. The HBM sled model ran to completion in a side-impact simulation with no instabilities or numerical artifacts observed (Fig. 2). The Y-chest-compression of the $F05_{75YO}$ model had a higher first peak than the $F05_{26YO}$ model, but they were generally similar. The $F05_{75YO}$ model predicted hard tissue failure in four ribs (from the 5^{th} to 8^{th} rib), whereas the $F05_{26YO}$ predicted hard tissue failure in three ribs (from the 5^{th} to 7^{th} rib).

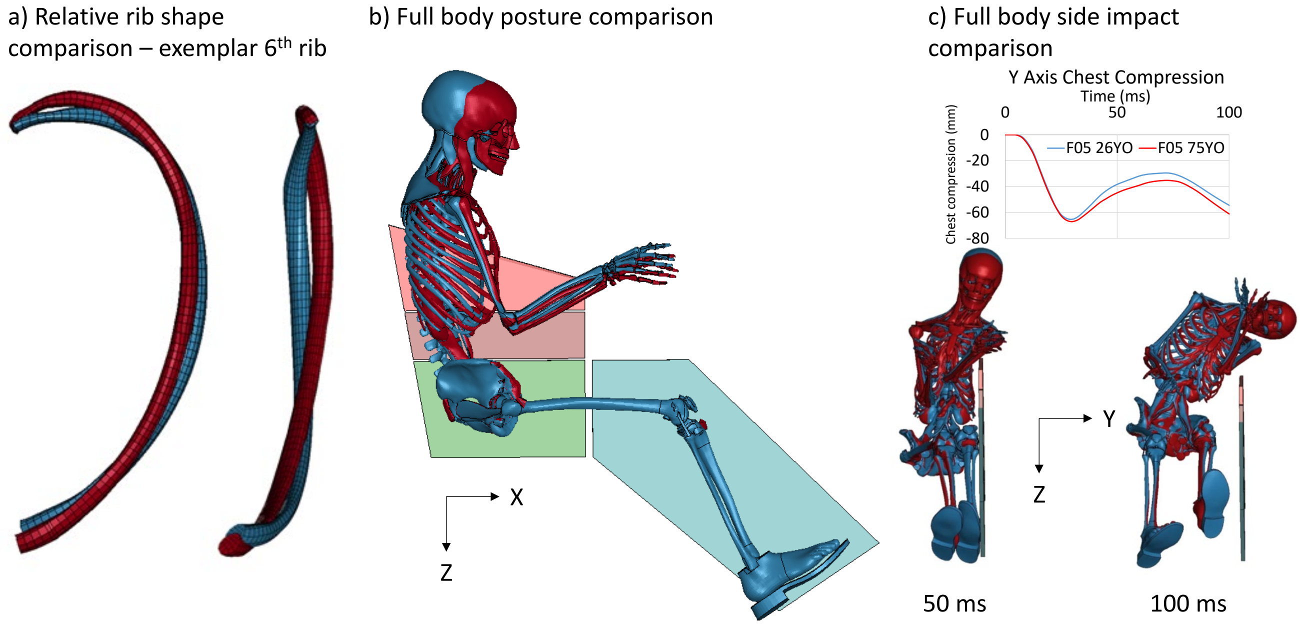

Fig. 2. Geometric comparison between the $F05_{24YO}$ model (blue) and $F05_{75YO}$ model (red): a) rib shape change with age; b) full-body posture change, including the change in thoracic kyphosis, rib shape, rib orientation and cervical lordosis associated with age; and c) $F05_{24YO}$ model (blue) and $F05_{75YO}$ (red) model in a side impact.

IV. DISCUSSION

The presented methodology augments existing HBM reposturing and morphing capabilities by allowing for rib shape morphing in addition to spine repositioning. The methodology was proven successful in terms of the achieved final rib geometry for an aged subject target geometry. The model was found to meet the commercial mesh quality thresholds at the full-body level and at the tissue level. The $F05_{75YO}$ model predicted similar lateral chest compression and a higher number of ribs exhibiting fracture; however, more work is needed in the assessment of the model as well as the modelling of the aged material properties and this will be included for future studies. This work will serve as the methodology testbed for future work towards subject-specific modelling for the aged population.

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VI. REFERENCES

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