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

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Background

Thoracic injury is the second leading cause of fatalities and severe injuries in motor vehicle crashes (MVCs). The shape, size, bone density, and cortical thickness of the thoracic skeleton are affected significantly by the occupant characteristics, such as age, gender, height, and body mass index (BMI). The thorax material and morphological variations are expected to affect thoracic injury mechanisms and tolerance, particularly for the vulnerable populations such as the elderly, women and the obese.

(1) As age increases, the human body thorax experiences a variety of changes, including both morphological changes (e.g., increased thoracic kyphosis) and material changes (e.g., osteoporosis).

(2) Recent studies showed that the morphology of the ribcage differed significantly with gender; for example, female subjects had more compliant torsos than male ones .

(3) Obese occupants also have increased injury risks for the thorax compared to occupants with normal BMI levels.

Computational modeling is a powerful and versatile tool to assess the effect of the morphological changes on thoracic injury risk.

Objective

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.

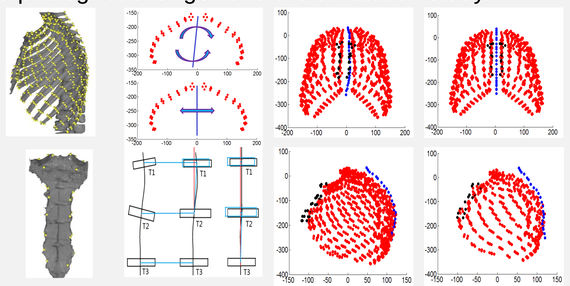
Methods

➢ Image segmentation and landmarks selection

45 thorax CT scans were obtained and mean values of the age, height and BMI were 44.6±20.7 years, 1.72±0.076 m and 28.2±5.6 kg/m^2. There are totally 1016 landmarks on the whole thorax, including ribs, spine and sternum.

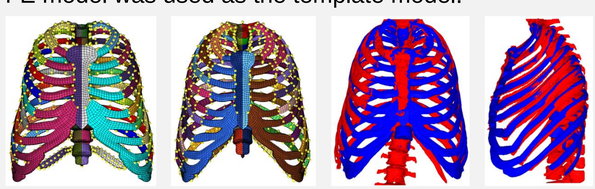
➢ Making symmetry for the thorax

For the statistical analysis and the development of the FE model, a totally symmetric model would be better for the morphological changes and the simulation study.



➢ Consistent mesh mapping

A method of RBF-TPS was used to map a baseline thorax FE model to the subjects. The THUMS 4 thorax FE model was used as the template model.



➢ PCA and parametric ribcage model

Principal component analysis (PCA) was used to acquire the principal components of the shape matrix G :

$P_k \approx S_k^T * G, \quad S_k * S_k^T = I$

S_k were the eigenvectors of the first k eigenvalues of G*G'.

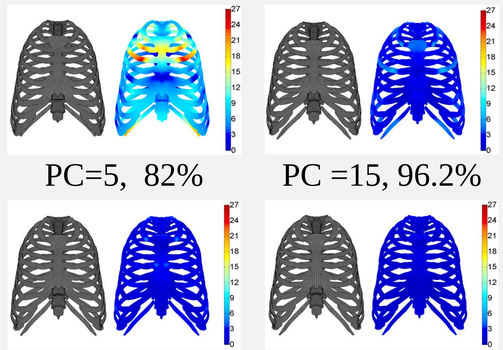
Using a linear regression model to represent every principal component by the age, gender, height and BMI:

$P_k = M * F + \varepsilon, \qquad M = (P_k - \varepsilon)F^+ \approx P_k F^+$

Results

➢ Number of Principal Components

The figure below shows the reconstructed thorax models using 5, 15, 27 and 35 principal components. The accumulated fractions of variance were 82%, 96.2%, 99% and 99.7% respectively. The average error distances for every node were 6.78mm, 2.13mm, 1.16mm and 0.68mm.



➢ Parametric ribcage model

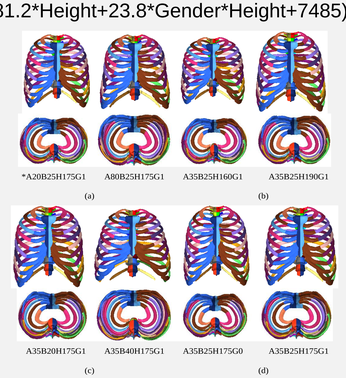
According to the PCA and the regression model, any subject with the parameters could be predicted using the following formula:

$M_{Pre}=[(F*M)*P+\bar{g}_1]*(7481.2*Height+23.8*Gender*Height+7485).$

(a) Older thorax had a larger width and depth than the younger thorax.

(b) Stature had the most significant effect on the thorax length.

(c) Men had a larger chest circumference.

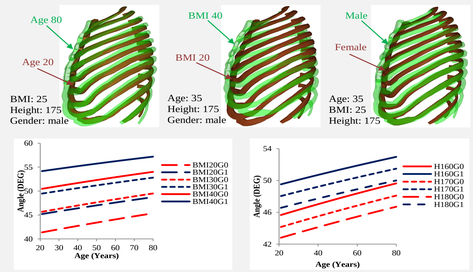


(d) BMI had a more significant effect on the lower ribcage than the upper ribcage, which made the thorax shape more like an "A", rather than a normal "H" shape.

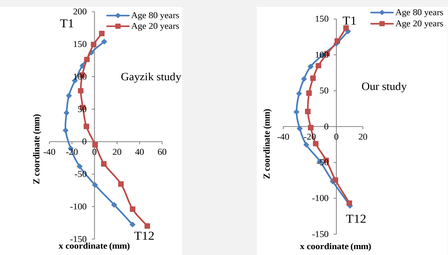
Discussion

➢ Morphologic changes with the human characteristics

As age and BMI increased, the ninth ribs angle had a steady increase, which is the same trend as the Kent et al. study.



Both the Gayzik et al. study and our study depicted increasing kyphosis with age.



Conclusion and future work

This study developed the parametric ribcage model accounting for age, gender, BMI and height based on the different subject CT scans. A thorax FE model could be easily predicted using a reasonable combination of parameters. Simulation analysis based on the predicted models should study the effect of morphological changes on thorax injury in future work.

Acknowledgement

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