Characterization of Cortical Bone Thickness Changes in the Thoracic Skeleton with Age and Sex

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Introduction

In motor vehicle crashes (MVCs), thoracic injuries are only surpassed by head injuries in relation to fatalities, number of serious injuries, and overall economic cost [1]. Better understanding of exact thoracic anatomy can allow for engineers and scientists to better design for the mitigation of thoracic injuries, especially as changes in anatomy occur based on age and sex of occupants.

Purpose

The objective of this study was to characterize cortical bone thickness changes in the thoracic skeleton with age and sex.

Methods

Rib cortical thickness measurements from the subjects in the study were collected using a validated algorithm [2, 3]. The algorithm calculates a reasonable cortical density that represents cortical bone from a subject's CT scan. The calculated cortical density is used in the algorithm to estimate the cortical thickness at thousands of locations on a rib surface model (Fig. 1). Point clouds of the inner and outer cortical bone surfaces are output for the entire ribcage.

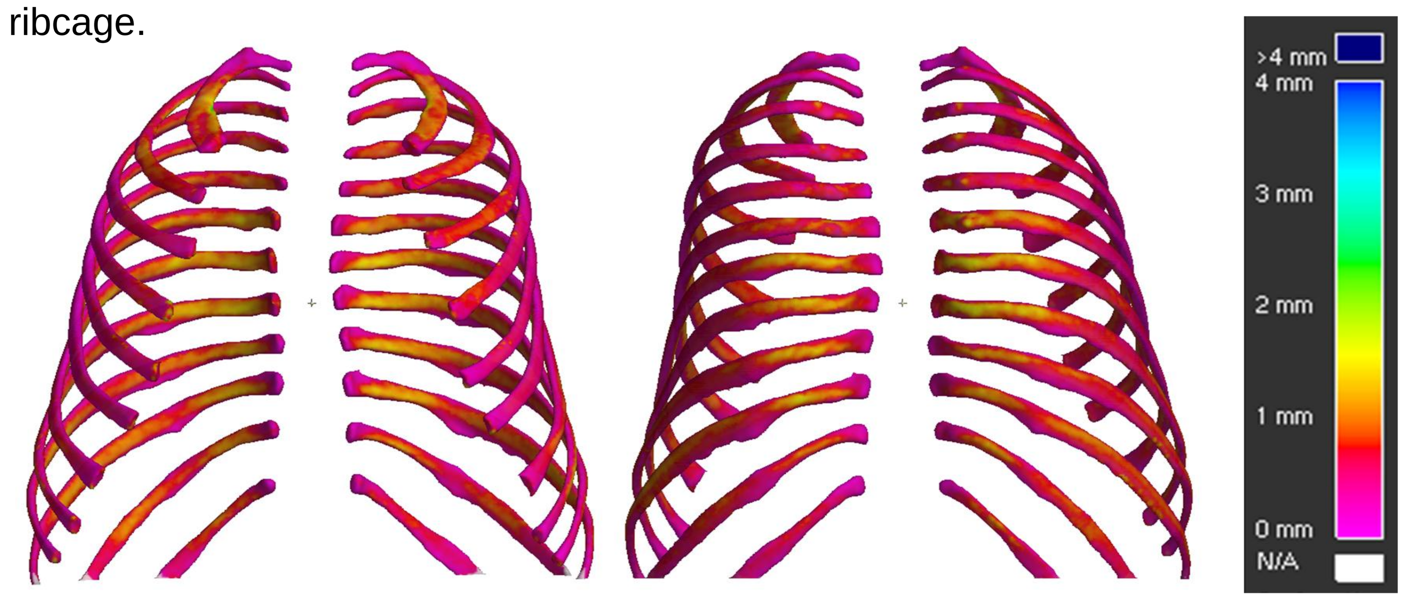

Figure 1. Anterior and posterior views of one subject's rib cage with cortical thickness measurements displayed using a color map on the surface models.

The cortical surface point clouds for the entire rib cage were sub-sectioned for regional analysis. The individual ribs were separated and labeled from the entire ribcage point cloud by comparing them to STL versions of each of the ribs. Each STL rib was imported and the corresponding points from the point cloud were selected using the algorithm DBSCAN [4], a density (number of points per volume) based clustering algorithm that assigns points in the same rib to the same group (Fig 2).

Using a modified cylindrical coordinate system, each individual rib was then sub-sectioned in a way that homologized the location of the thickness measure in relation to the rib as a whole. The "Z" coordinate is the distance along the centerline through the rib anteriorly to posteriorly (Fig 3). For each rib cross-section, a "thickness" coordinate describes the thickness measurement while the "angle" coordinate describes the angular location of the thickness measurement (Fig 3). The rib was then divided into cross sectional rings by moving along the centerline and dividing the rib into rings perpendicular to the centerline at discrete measurements, based on the characteristic length of the rib and rib level (Fig 4).

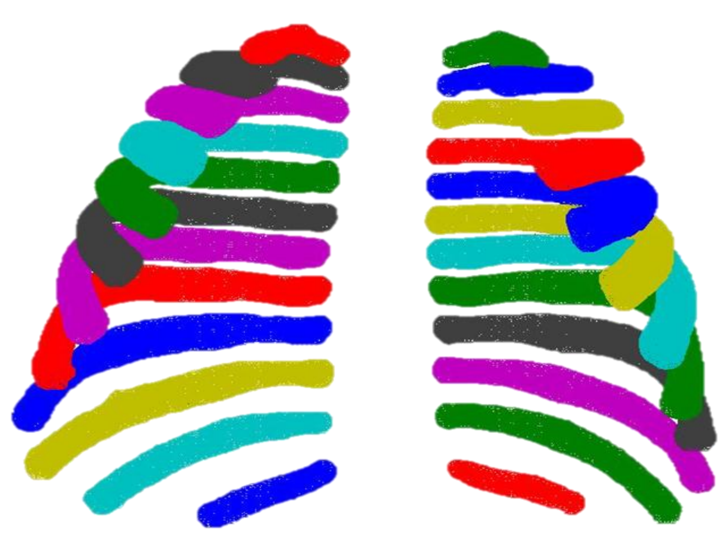

Figure 2. An entire ribcage point cloud separated into individual ribs.

Methods, Cont.

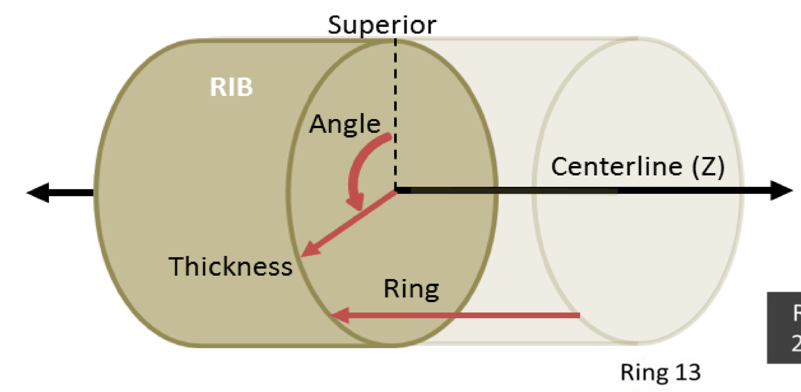

Figure 3. Depiction of the modified cylindrical coordinate system associated with characterizing the sub-sections of each of the ribs.

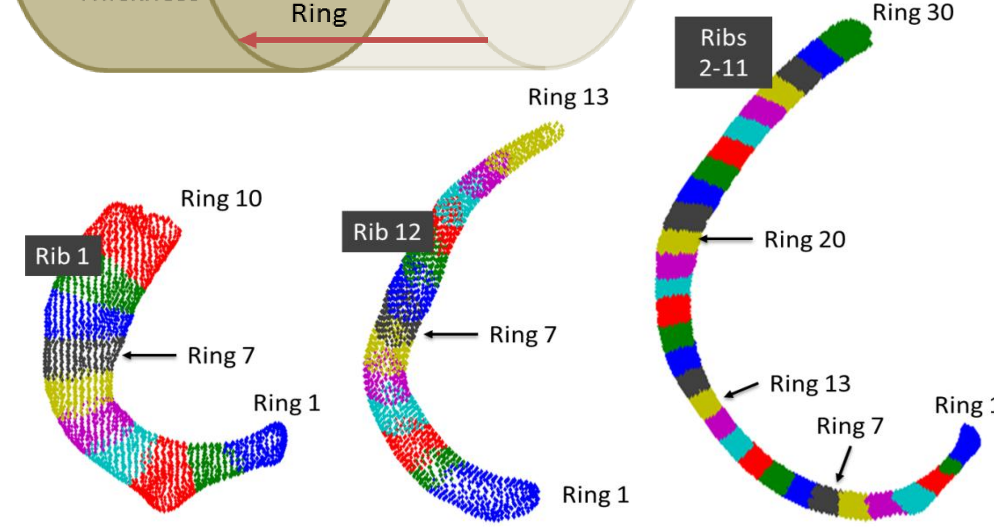

Figure 4. Ribs sectioned into cross-sectional rings and the number of rings per rib. Large ribs (2-11) have 30 rings, while ribs 1 and 12 have 10 and 13 rings, respectively.

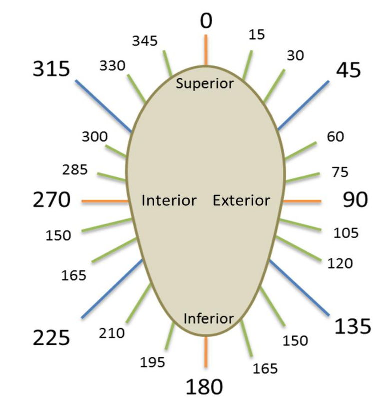

Figure 5. Angles around the circumference of a rib ring that divide the cross-sectional ring into angular regions.

The cross-sectional rings were then separated into angles corresponding to anatomical quarters representing the superior, interior, inferior and exterior portions of the rib (Fig 5). The thickness measurements within a given angular section of the cross-sectional ring were averaged to compute an average thickness for a given sub-section on a subject's rib (Fig. 6). The sub-sectioning methodology was applied to every subject rib in the study so that changes in local rib thickness could be compared with age and sex. The average thickness measurement for each sub-section is associated with an identification number that relates sex, age, rib level and laterality, and sub-section information so that all average thickness values collected for a given rib region for all subjects can be regressed with age and sex, and analyses can be completed on the results.

Results

A total of 222 patients were analyzed using the methods described above. In total, cortical thickness measurements have been collected and regionally assigned to homologous locations so that age and sex-related comparisons can be made. Fig. 6 illustrates the original thicknesses and average thicknesses for a lateral cross-sectional ring from one 35 year old female's left 6th rib (cross-sectional ring 15 of 30).

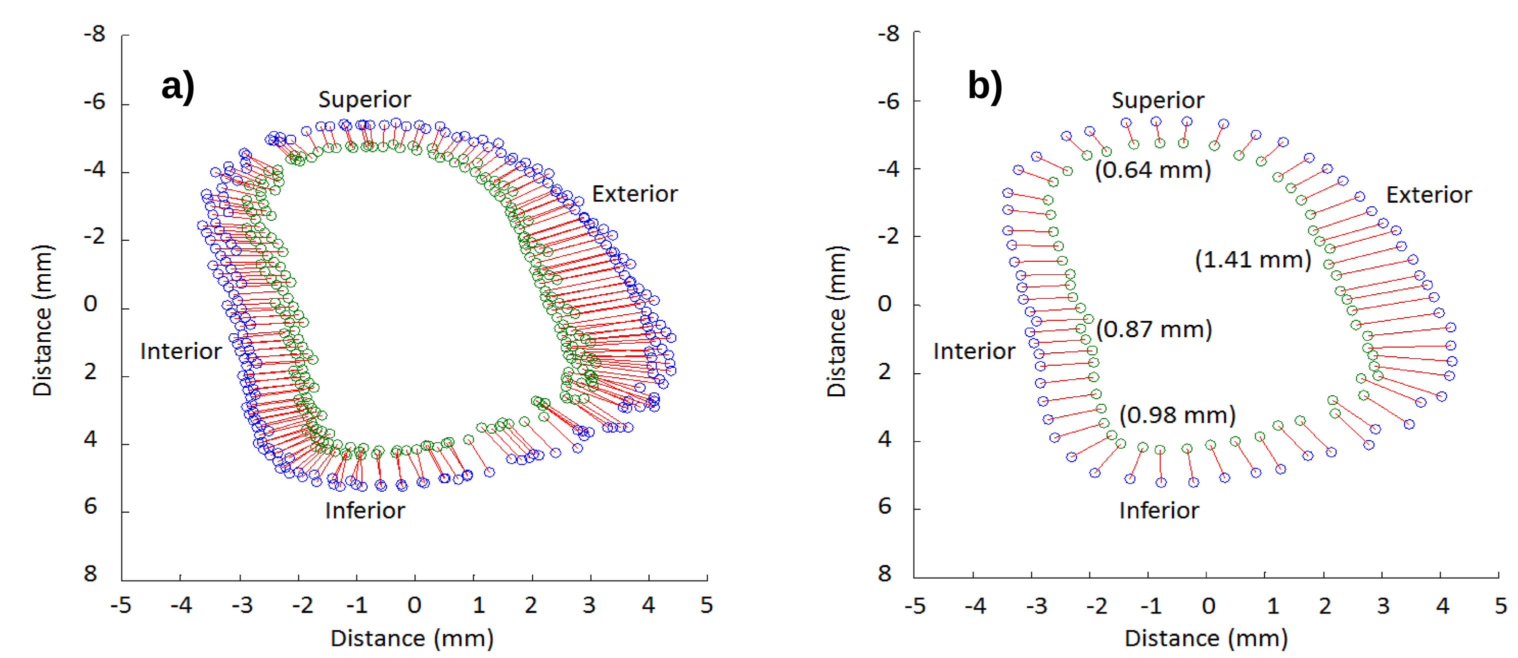

Figure 6. Cortical thickness from a lateral cross-sectional ring of a 35 year old female's left 6th rib. a) Original point cloud for a single cross-sectional ring including inner and outer points (216 inner/outer pairs). b) Corresponding averaged inner and outer points within the cross-sectional ring

Results, Cont.

A sample regression fit for a single male subsection (left 5th rib, 3rd ring, interior portion) for ages 10-100 is shown in Fig. 7 depicting an increase in cortical thickness through the young ages and then a decrease in thickness into the elderly ages. Fig 8 shows the evaluated results of the regression equations for all subsections for males and females at ages 20, 40, 60, and 80.

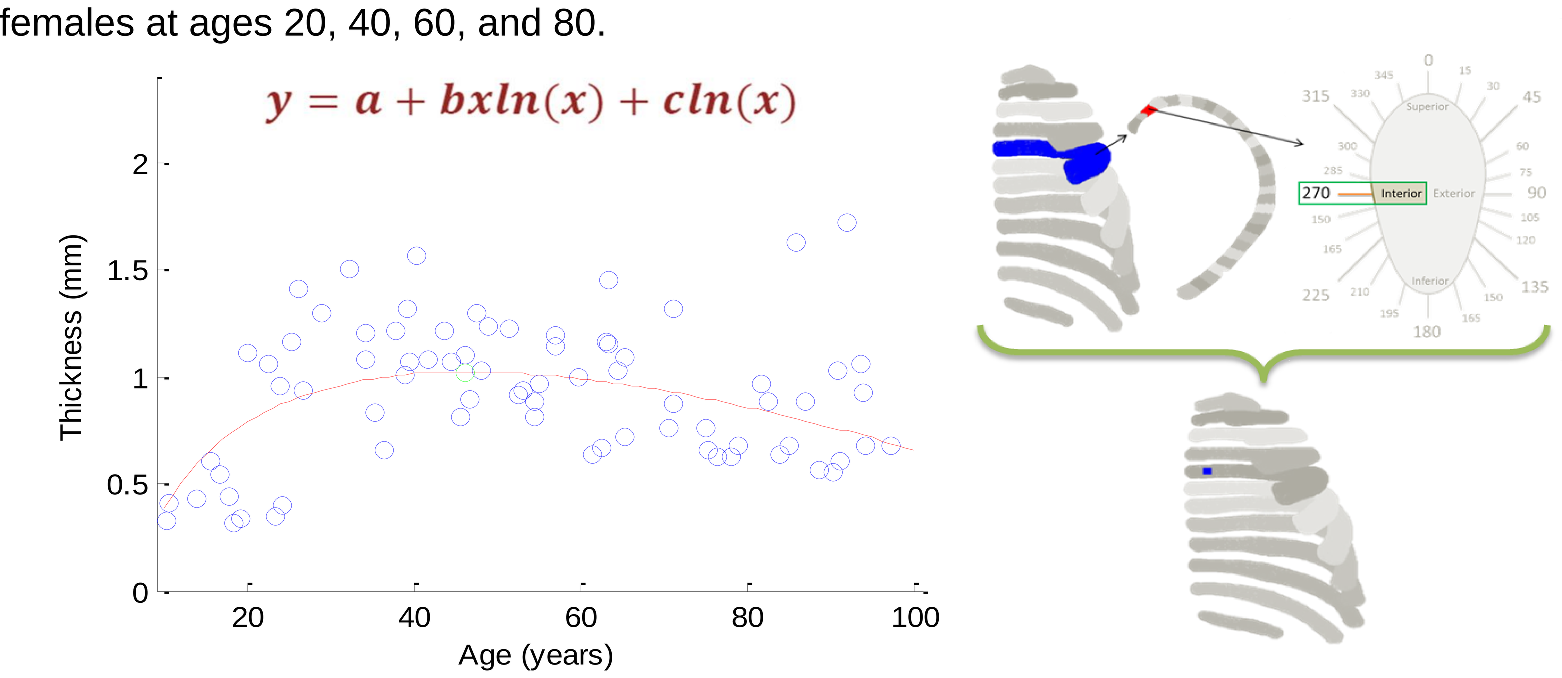

Figure 7. Regression for cortical thickness within a male rib subsection with age (10-100 years).

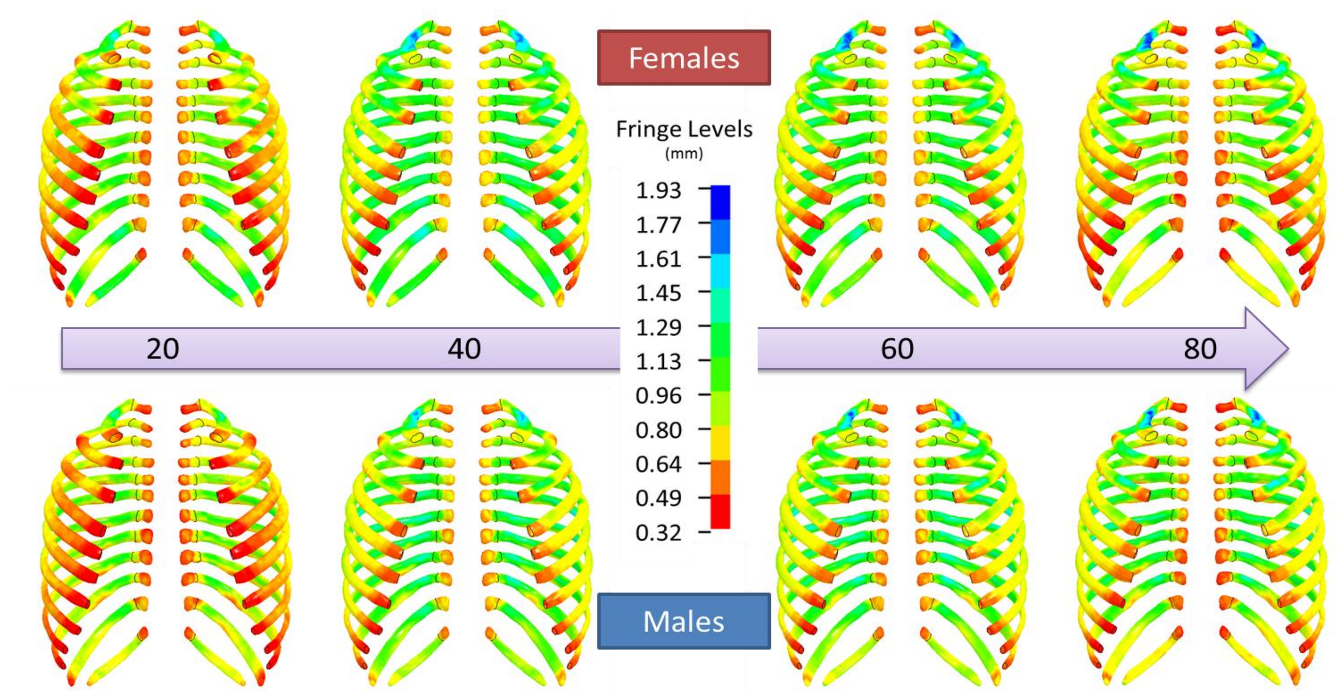

Figure 8. Evaluated results from the regressions of cortical thickness for males and females for the entire ribcage for ages 20, 40, 60 and 80.

Conclusions

A cortical density based algorithm was used to estimate cortical thicknesses of the ribs from 222 subjects. Tens of thousands of thickness measurements were collected from each rib and the measurements were grouped into angular sub-sections within cross-sectional rings defined along a rib centerline. The sub-sectioning methodology employed in this study assigned cortical thicknesses collected from all subjects to homologous rib regions so that age and sex-based comparisons could be made. In the future, the rib cortical thicknesses will be implemented into age and sex-specific finite element models used for MVC injury prediction.

Acknowledgements

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References

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