Utilization of a Novel Method for Measuring Cortical Thickness to Investigate Variation with Age in Male Human Ribs

Michelle M. Murach, Andrew Bazyk, Elina Misicka, Yun-Seok Kang, Kevin Moorhouse, Amanda M. Agnew

I. INTRODUCTION

As computational models of the human thorax are increasingly utilized to investigate injury risk in car crash scenarios, accurate rib cross-sectional geometry becomes critical to ensure biofidelity of these models. Cortical thickness (Ct.Th) of ribs has been shown to be an important geometric parameter for obtaining accurate number of fractures, fracture location, and structural properties such as failure displacement and loads [1-2]. Although many methods have been utilized to explore Ct.Th of human ribs [3-5], they have been limited by poor resolution of cross-sectional images, subjectivity and inaccuracy in defining the orientation of Ct.Th lines, and small sample sizes. Therefore, the aim of this study was to establish an objective and accurate methodology for measuring Ct.Th of human ribs from microscopic cross-sectional images and investigate trends with age.

II. METHODS

The sample consisted of 110 mid-thoracic (levels 4-7) ribs from 60 male subjects ranging from 18-88 years of age (mean of 50 ± 20 years). Whole ribs were tested in a pendulum fixture simulating a frontal impact to the thorax [6]. Sections were removed from the variable location of fracture and were classified based on their location with respect to the curve length (Cv.Le) of the rib as either anterior (70-100% of Cv.Le) or lateral (30-70% of Cv.Le). Slides were prepared according to standard histological procedures and cross-sectional microscopic images were obtained at 40x magnification with an Olympus VS120 slide scanner, resulting in image resolution of ≥ 582 pixels/mm.

Measurements were manually made in cellSens Dimension® to define periosteal and endosteal borders (Fig. 1). A custom MATLAB script was written to measure Ct.Th for each cortex: pleural, cutaneous, superior, and inferior. The neutral axes were calculated (Fig. 1) as well as height of the rib cross section (distance from most superior point to most inferior) and width (distance from most cutaneous point to most pleural). Ct.Th was measured for each cortex from -10% to +10% of either the height or width of the rib, centered on the neutral axes. An edge detection function was used to identify the periosteal and endosteal borders for each cortex. The script iterates through each point on the periosteal border and calculates a tangent line for each point using the local curvature. A perpendicular line is then drawn to each tangent line and the line continues until it reaches the endosteal border. A total of ~100 lines are drawn for each cortex, the length of each line is calculated, and all lines are averaged to obtain Ct.Th for each cortex.

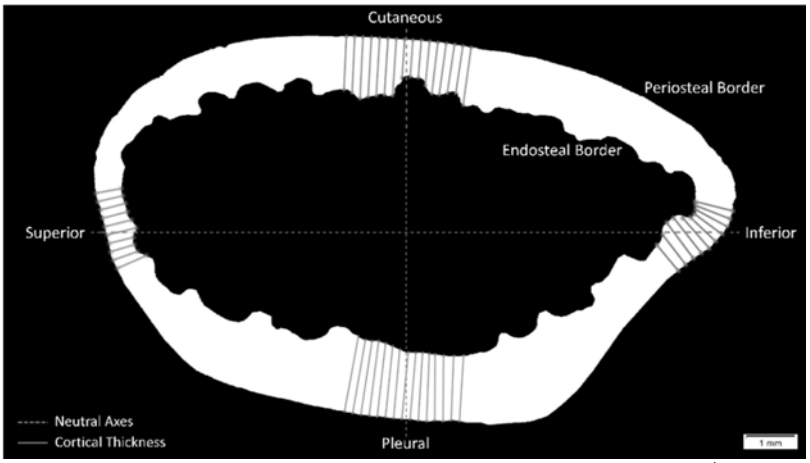

Fig. 1. Cross-sectional image of a rib including neutral axes with every 10th Ct.Th line drawn

M.M. Murach is a MS student in Biomedical Engineering at The Ohio State University in Columbus, OH, USA (+1-440-668-4945, murach.2@osu.edu). M.M. Murach, A. Bazyk, E. Misicka, Y.S. Kang, and A.M. Agnew are affiliated with the Injury Biomechanics Research Center (IBRC), The Ohio State University, USA. K. Moorhouse is affiliated with the National Highway Traffic Safety Administration (NHTSA), Vehicle Research & Test Center (VRTC), USA.

III. INITIAL FINDINGS

There were significant differences between anterior and lateral Ct.Th for all cortices except inferior (2-sample t-test, $p<0.01$). Significant relationships with age (linear regression, $p<0.01$, bolded) can be found in Fig. 2 as well as minimum and maximum values of Ct.Th for each cortex and section location.

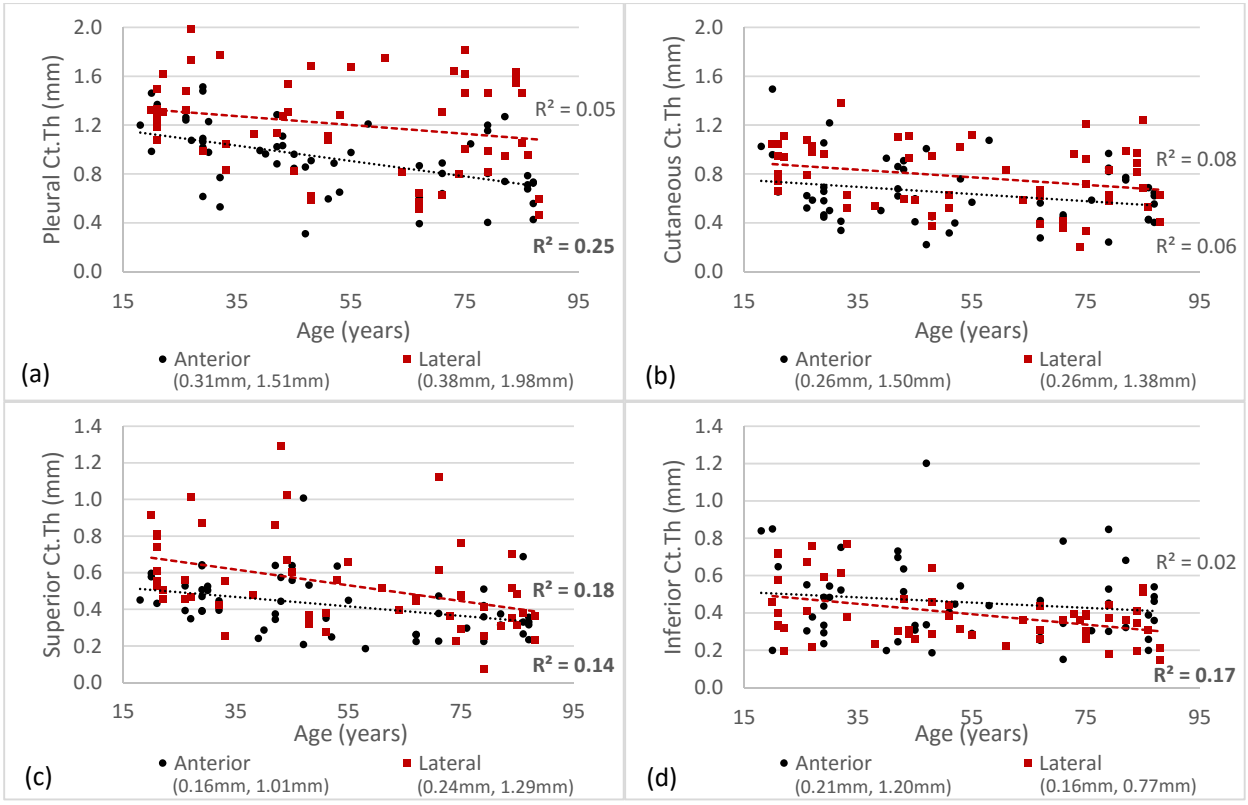

Fig. 2. Ct.Th for (a) pleural, (b) cutaneous, (c) superior, and (d) inferior cortices by age and separated by section location. Significant R^2 values in bold. Min and max values of Ct.Th in parentheses

IV. DISCUSSION

The novel method established and utilized here is deemed superior to existing methods because of its objective nature, increased precision resulting from improved resolution of microscopic images compared to other imaging modalities, and large number of Ct.Th lines for each cortex. The range of values for Ct.Th reported here are comparable to those found in previous studies. Study [4] found Ct.Th values for anterior sections ranging from 0.34-1.35mm for pleural cortices, 0.16-0.79mm for cutaneous cortices, 0.18-1.13mm for superior cortices, and 0.07-1.13mm for inferior cortices, as well as 0.79-1.83mm for pleural cortices, 0.22-1.46mm for cutaneous cortices, 0.32-1.46mm for superior cortices, and 0.3-1.75mm for inferior cortices for lateral sections from six male subjects ranging from age 42-81 years (rib levels 4-7). With the largest R^2 value being only 0.25, preliminary work indicates that age, although statistically significant, is not a strong predictor of Ct.Th. Future work will investigate variation in Ct.Th with respect to rib level as well as increase the sample to include females to explore potential sex differences.

V. REFERENCES

[1] Kent RW et al., Stapp Car Crash J., 2005.
[2] Li Z et al., Med. Eng. Phys., 2010.
[3] Mohr M et al., J. Biomech., 2007.
[4] Kemper AR et al., Stapp Car Crash J., 2007.
[5] Perz R et al., J. Mech. Behav. Biomed. Mater., 2015.
[6] Agnew AM et al., J. Mech. Behav. Biomed. Mater., 2015.

Acknowledgements: Thank you to NHTSA for providing funding. Thanks to John H. Bolte IV, Tim Gocha, Victoria Dominguez, Jason Stammen, Mark Whitmer, Michelle Whitmer, Lifeline staff, and all donors.