CROSS-SECTIONAL GEOMETRY OF HUMAN RIBS

Eduard Abrams, Marcus Mohr, Christine Engel, and Michael Bottlang

Biomechanics Laboratory, Legacy Clinical Research & Technology Center, Portland, OR, USA
Email: mbottlan@lhs.org

INTRODUCTION

This study describes geometric parameters of rib cross-sections along human cadaveric ribs three through nine. The shape, size, and cortex thickness apparent on rib cross-sections varies within each rib and between ribs. However, only limited information on cross-sectional geometry over the complete rib length is available to date [Roberts et al., 1970 and Yoganandan et al., 1998]. Results of this study provide geometric descriptors of human rib anatomy as a scientific basis for the advancement of hardware for rib fracture fixation. Such surgical fixation of multiple segmental rib fractures can aid restoration of pulmonary function in a timely manner to reduce mortality associated with prolonged mechanical ventilation [Lindenmaier et al., 1990].

METHODS

Right ribs three through nine were harvested from five non-embalmed human cadavers (59 ± 13 years, 71 ± 30kg, 3 male, 2 female). Using a custom circular saw, 2 mm thick cross-sections were excised at 5%, 25%, 50%, and 75% of rib length (Fig. 1a). The rib length was defined from the tubercle (0%) to the costo-chondral junction (100%) in each rib. The 5% cross-section was located between the tubercle and angle. Cross-sectional specimens were transferred directly onto an x-ray cassette. The outer cortex of each specimen was aligned parallel to the right edge of the cassette, and contact radiographs of each cross-sectional specimen were obtained. For quantitative image analysis with MATLAB (MathWorks, Natick, MA), contact radiographs were scanned in 8-bit grayscale mode at a resolution of 800 pixels per inch. Successive gray scale equalization and thresholding was applied to objectively discretize cortical and trabecular structures.

Cortex Thickness (t_C): To quantify the thickness of the superior (t_{sup}), inferior (t_{inf}), inner (t_{inn}), and outer (t_{out}) cortex of each cross-section, a bounding box was fitted to each cross-sectional image. The side lengths of the bounding box represented the height (h) and width (w) of each cross-section (Fig. 1b). t_C was measured at the intersections of the cortex with the horizontal and vertical symmetry lines of the bounding box. t_C was also measured 0.75 mm above and below at each intersection to obtain average t_C reports (t_{sup}, t_{out}, t_{inf}, t_{inn}) over 1.5 mm regions of interest.

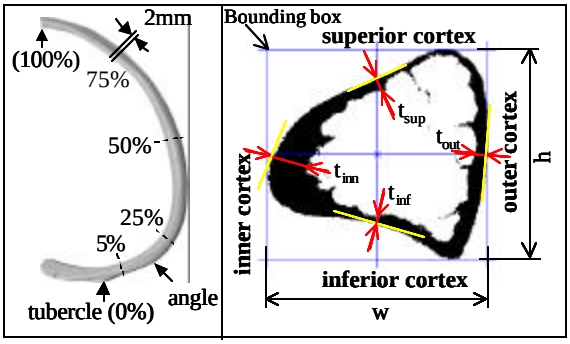

Figure 1: (a) Location of cross-sections; **(b)** Geometric parameters.

Cross-Sectional Area: The total area of each cross-section and the cortex area itself were computed with MATLAB. Finally, the area of the medullary canal was calculated by subtracting the cortex area from the total cross-sectional area.

RESULTS

The cross-sectional shape varied among specimens excised at the four locations along each rib, but remained similar for corresponding locations on ribs three through nine (Fig. 2). As determined by the bounding box, the average cross-sectional height among ribs three through nine was 10.3±1.8 mm, 13.5±3.1 mm, 12.1±2.9 mm, and 12.2±3.1 mm and the width was 7.5±1.8 mm, 7.1±2.1 mm, 6.9±2.1 mm, and 12.2±3.1 mm at 5%, 25%, 50%, and 75% locations, respectively. The inner cortices were on average the thickest (1.1±0.5 mm). The average thickness of t_{out}, t_{sup} and t_{inf} was 0.8±0.4mm, 0.5±0.4 mm, and 0.5±0.3mm, respectively. The outer, superior, and inferior cortices were thickest at 5 % rib length (Figure 2).

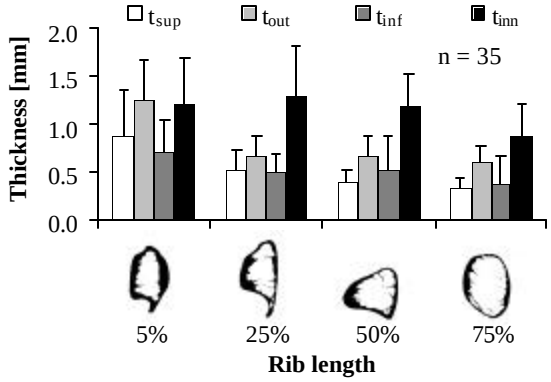

Figure 2: Average cortical thicknesses, and exemplary cross-sections

The cortical thickness and the rib height and width are listed in Table 1 for ribs three through nine. The average cortical area of ribs three through nine decreased from 26.3 mm^2 to 16.3 mm^2 from cross-sections at 5% to 75% rib length, respectively. The medullary area increased from 29.9 mm^2 at 5% to 41.2 mm^2 at 75% (Figure 3).

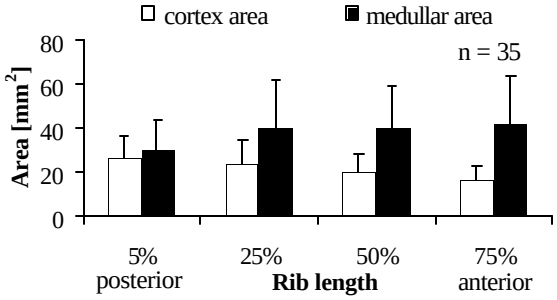

Figure 3: Cortical and medullary area

DISCUSSION

Results of this study expand the limited set of data available on cross-sectional rib geometry to date. Results quantify for the first time characteristic differences in cortex thickness distribution within rib cross-sections over the rib length. It shows the non-uniform distribution of cortex and the pronounced change of the cross-sectional rib shape over the rib length. This quantitative information has direct implications to advanced rib osteosynthesis and techniques.

REFERENCES

Yoganandan, N., Pintar, F.A. (1998*). J Biomech Eng*, **120**, 100-104.

Roberts, S., Chen, P. (1970*). J Biomechanics*, **3**, 527-545.

Lindenmaier, H.L., Kuner, E.H., et al. (1990). *Unfallchirurgie*, **16**, 172-177.

ACKNOWLEDGEMENTS

Supported by Legacy Research Foundation.

Table 1: Cortex thicknesses and outer dimensions in mm (n = 20)

	Rib 3	Rib 4	Rib 5	Rib 6	Rib 7	Rib 8	Rib 9
t_{sup}	0.6 ± 0.4	0.6 ± 0.5	0.4 ± 0.3	0.5 ± 0.3	0.5 ± 0.3	0.6 ± 0.4	0.6 ± 0.3
t_{out}	0.7 ± 0.3	0.7 ± 0.3	0.8 ± 0.3	1.0 ± 0.5	1.0 ± 0.4	0.9 ± 0.5	0.8 ± 0.4
t_{inf}	0.5 ± 0.3	0.5 ± 0.3	0.5 ± 0.3	0.5 ± 0.3	0.5 ± 0.2	0.6 ± 0.4	0.6 ± 0.3
t_{inn}	0.9 ± 0.4	0.9 ± 0.3	1.1 ± 0.4	1.4 ± 0.4	1.4 ± 0.4	1.2 ± 0.6	1.1 ± 0.4
h	11.3 ± 2.5	11.6 ± 2.6	11.4 ± 2.6	11.8 ± 2.6	12.8 ± 2.8	13.1 ± 3.6	12.0 ± 3.8
w	6.0 ± 2.0	6.8 ± 2.0	7.2 ± 1.9	7.6 ± 1.8	7.4 ± 1.7	6.5 ± 2.1	6.4 ± 1.9