Structural and Effective Material Properties of the Anterior, Lateral, and Posterior Human Rib Bone

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Abstract

Introduction: *The elastic modulus of human rib bone derived from tensile coupon tests (13.9GPa) could be too high for applications in Finite Element (FE) modeling of the human thorax, as the homogenous elements lack the microstructure of typical rib bone. In this study MicroCT scans of ribs from three cadavers were used to determine homogenized elastic moduli of ribs that could be applied to solid FE homogenous rib models.*

Materials and Methods: *The specimens used in this study, M412-62 for example, were named by gender (M), cadaver ID (412), and age (62). To obtain structurally correct models, 3mm thick cross sections of ribs 1-7 at anterior, lateral, and posterior positions were scanned with a MicroCT scanner at 15μm or 30μm resolution. MIMICS 16.0 was used to generate a segmented mesh for FE simulations in Abaqus CAE 6.9 to determine structural properties including structural efficiency, defined as stiffness normalized by bone volume. Rib bone elements were modeled as linear elastic (E=13.9GPa, v=.3). The polar moment of inertia for each rib was calculated using a custom Matlab script. From these results, an elastic modulus was determined for a solid, homogenous model.*

Results and Discussion: *Lateral and posterior rib 7 of the youngest cadaver had the greatest stiffness and polar moment of inertia. Overall, the oldest cadaver had ribs consistently lower in stiffness and polar moment of inertia than the ribs of the younger cadavers. The average bone volume for anterior ribs (14±5mm3) was less than lateral (28±7mm3) and posterior ribs (33±6mm3). The anterior rib sections had lower results in all structural properties. Structural efficiency was similar among lateral and posterior ribs of all 3 cadavers and at all rib levels (14100±400N/mm/mm3). The anterior ribs were much lower in structural efficiency (9600±500N/mm/mm3), with Rib 5 removed as an outlier due to lack of microstructure (4.79mm3). The general trend for all other structural properties analyzed was to decline to a minimum at rib level 3 or 4 upon increasing to rib 7. Furthermore, the posterior ribs were stiffer than the lateral ribs by 30%, while lateral ribs were 90% stiffer than anterior ribs. Interestingly, while the stiffness and polar moment of inertia of the rib levels varied, the homogenized elastic modulus remained similar between rib levels and cadavers, but varied between anterior (1.6±.4*

GPa), lateral (4.7±.7 GPa), and posterior regions (6±1 GPa). These results are an indication that rib bone structural properties decrease with age, but the homogenized material properties remain relatively constant, even between individuals. Calcifications around the costo-chondral junction could have altered the structural properties of the anterior ribs.

Conclusion: *An elastic modulus between 3GPa and 8GPa dependent on rib location is more suitable than 13.9GPa when modeling the rib with a solid homogenous cross section. The results from this study can improve whole body FE models. Further studies could investigate a section of anterior rib farther from the cost-chondral junction. Future work could evaluate the cortical rib compartment alone to provide an elastic modulus useful in hollow cross sectional models.*