Effects of Strain Rate and Age on the Tensile Material Properties of Human Rib Cortical Bone

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Background/Objective: The thorax is one of the most frequently injured body regions in motor vehicle collisions, and severe thoracic injuries, such as multiple rib fractures, have been shown to increase mortality risk. Although finite element models (FEMs) of the human body are frequently used to evaluate thoracic injury risk, the accuracy of these models is dependent on the biomechanical data used to validate them. Research has shown that the material properties of bone can vary with respect to age and loading rate. However, previous studies that have evaluated the tensile material properties of human rib cortical bone have been limited to a small number of subjects, a narrow age range, and one loading rate. Therefore, the objective of this study was to evaluate the effects of age and loading rate on the tensile material properties of human rib cortical bone over a wide range of subject demographics.

Methodology: Sixty-one (n=61) subjects (M=32, F=29) ranging in age from 17-99 yrs. (Avg.=56 yrs.) were used in this study. Two rectangular coupons of rib cortical bone were obtained from each subject and then milled into a dog-bone coupon. For each subject, one coupon was tested to failure in tension on a material testing system at a targeted strain rate of 0.5 strain/s, while the other coupon was tested at 0.005 strain/s. The test setup consisted of a load cell to measure axial load and an extensometer to measure displacement within the gage length. The elastic modulus, failure strain, failure stress, and strain energy density (SED) were then calculated for each test. Correlation analyses and paired t-tests were conducted to determine if the material properties varied significantly with respect to age ($p \leq 0.05$) and loading rate ($p \leq 0.05$), respectively.

Results: Fifty-eight (n=58) coupons were successfully tested at 0.5 strain/s, and fifty-eight (n=58) coupons were successfully tested at 0.005 strain/s, with fifty-five (n=55) matched pairs. At 0.5 strain/s, failure stress (R^2=0.56, $p<0.0001$), failure strain (R^2=0.49, $p<0.0001$), modulus (R^2=0.24, $p<0.0001$), and SED (R^2=0.62, $p<0.0001$) had significant negative correlations with age. At 0.005 strain/s, failure stress (R^2=0.33, $p<0.0001$), failure strain (R^2=0.54, $p<0.0001$), and SED (R^2=0.57, $p<0.0001$) had significant negative correlations with age. When comparing loading rates, failure stress ($p<0.001$) and SED ($p=0.0081$) were significantly higher at 0.5 strain/s than 0.005 strain/s.

Conclusions: The results showed that the material properties of human rib cortical bone varied significantly with respect to both age and loading rate. Failure stress, failure strain, and SED decreased with increased age for both loading rates. Failure stress and SED showed a significant difference with respect to loading rate. However, the R^2 values only ranged from 0.24-0.62, indicating that there may be other underlying variables that better account for the variance within a given population. Overall, this is the first study to analyze the effects of age and loading rate on tensile material properties of human rib cortical bone using a reasonably large sample size. The data from this study will improve the ability of FEMs to accurately assess thoracic injury risk for all vehicle occupants.