Linear Effects of Subject-Level Variation on the Structural Properties of Human Ribs

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The human thorax is one of the most commonly-injured areas of the body in motor vehicle crashes, and rib fractures in particular are highly prevalent. In order to gain a better understanding of the loading capabilities of human ribs, an ongoing project is aimed at understanding variation in the structural properties of human ribs. One hundred and eighteen sixth-level ribs from 106 post-mortem human subjects were individually impacted in a dynamic experiment simulating a frontal loading scenario. Peak force (F_{PEAK}) and linear structural stiffness (K) were calculated for each impact. Demographic factors of each subject were tracked per rib, including age at time of death (yrs), sex, stature (cm), and body mass (kg). A multivariate linear regression model was constructed to examine the effect of the demographic factors on each structural property. All continuous predictors were centered and standardized using standard deviation values, in order to reduce any potential effects of collinearity. Two regression models were created for each response variable: the first examined the effects of demographic predictors independently on the structural property, and the second model explored the effects of demographic predictors as well as their potential interactions. When the effects of the predictors alone on the response variables were examined, age and sex had significant influence on both peak force and stiffness (respectively, $p<0.0001$ and $p=0.002$ for peak force, $p=0.025$ and $p=0.001$ for stiffness). Body mass and stature had no significant effect on either structural property, with p-values greater than 0.30 for both predictors in both response variables ($\alpha=0.05$). When coefficient terms examining the interactions of predictors were included in the F_{PEAK} model, the influence of age and sex remained statistically significant ($p=0.001$, $p=0.009$, respectively), and the influence of mass and sex remained statistically insignificant ($p=0.567$, $p=0.990$, respectively). There were no significant interactions between any predictors. However, when the K model was expanded to include predictor interaction coefficients, age ($p=0.007$), sex ($p=0.001$), and body mass ($p=0.024$) were found to have significant influence on K. There was also a statistically significant interaction between body mass and sex ($p=0.004$), but not for any other predictors. R-squared values were remarkably low across all models explored here. For the F_{PEAK} model, the R-squared values for the model with predictors and the model with predictors and their interactions were 0.33 and 0.36, respectively. Similarly, for the K model, the R-squared values were 0.18 and 0.27, respectively. To summarize, subject level demographic variables provide statistically significant prediction of peak force and stiffness in many cases, but explain only a small amount of overall variation in rib properties. Future work will investigate if correlation coefficients can be increased by examining the influence of other rib-specific variables such as robusticity and section modulus. The results from this study contribute to the larger effort to improve the biofidelity of anthropomorphic test devices and computational human body models.