A Preliminary Exploration of Contribution of the Individual Rib to Dynamic Response of the Human Thorax

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Although great strides have been made in improving frontal crash protection of the thorax, rib fractures are still prevalent and a leading cause of morbidity and mortality. In order to establish and improve response targets and injury thresholds, which are critical to the design and validation of biofidelic Anthropomorphic Test Devices (ATDs) as well as computational human body models, extensive thoracic testing must be conducted. Over the past several decades, a large body of work has been undertaken to obtain thoracic and individual rib properties. However, such testing has primarily focused on 50th percentile males and relies heavily on scaling in order to apply findings to other populations.

Component level testing (i.e., individual bones) has the advantage of capturing large amounts of variation in subject level characteristics (sex, age, stature, etc.). To this end, 287 individual mid-level ribs from 158 post-mortem human subjects were tested in a dynamic bending scenario simulating a frontal impact to the thorax. The subjects consisted of 107 males and 51 females, ranging from 4-108 years of age. Force-deflection curves were used to calculate structural stiffness (Krib). Although these data have allowed for an extensive exploration of variation in response of the individual rib to dynamic loading, a gap remains in the ability to understand these findings in the context of the intact thorax.

In order to address this gap, a series of non-injurious frontal impacts (< 20% chest compression) were conducted on four post-mortem human subjects. To quantify the effect of all thoracic components, each subject was tested in three subsequent tissue states: intact, denuded (superficial tissue removed), and eviscerated (superficial tissue and viscera removed) using a 23kg pneumatic ram at speeds ranging from 2-3m/s. Force-deflection curves from each impact were utilized to calculate thoracic stiffness (K_{intact}, $K_{denuded}$, and $K_{eviscerated}$). Following eviscerated testing, mid-level ribs were removed and tested to failure in the dynamic bending scenario described above. Preliminary data indicate that removal of superficial tissue results in an average of 25% reduction in thoracic stiffness (K_{intact} versus $K_{denuded}$) and subsequent removal of viscera resulted in an additional 45% decrease ($K_{denuded}$ versus $K_{eviscerated}$). Furthermore, the application of a linear spring model in which each rib is treated as a spring acting in parallel was developed in order to be able to use individual rib response data to predict thoracic response data. Initial analyses show that the model has the potential to predict $K_{eviscerated}$ from K_{rib}, with percent differences between the predicted and experimental $K_{eviscerated}$ as low as 5%.

The ultimate goal is to develop a transfer function which utilizes the response of the individual rib to predict the response of the thorax from which it came. This transfer function can then be applied to the vast amount of data already collected on individual rib response and allow for the generation of estimated thoracic response data for all populations, with pediatric specimens being of particular interest. These data could be used to improve thoracic response targets and help assess the biofidelity of current ATDs.