Characterizing the Inhomogeneity of Aorta Mechanical Properties and its Effect on the Prediction of Injury

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Introduction:

Traumatic Aortic Rupture (TAR) is the 2nd leading cause of death in automotive accidents with most incidences taking place at the isthmus. Finite Element (FE) models of the thorax are developed in order to predict the occurrence of TAR and gain better insight into its mechanisms. In most FE models of TAR, aorta is assumed to be homogenous. We hypothesized that including the inhomogeneous material properties of aorta in the FE models can significantly improve their ability to predict TAR. This study investigates the inhomogeneity of porcine descending thoracic aorta (DTA) using a custom-made nano-indentation technique. The results were implemented in the Global Human Body Model (GHBM), and the changes in aorta stresses and strains distributions due to inhomogeneity, in a frontal chest impact loading scenario were evaluated.

Materials and Methods:

Fresh porcine DTA specimens were excised from seven pigs and their inhomogeneous viscoelastic behavior, in the axial, circumferential, and radial directions were characterized with 100 micrometer spatial resolution. Based on the obtained material properties and data from the literature, TA was divided into five sections to make an inhomogeneous model (IHM): ascending thoracic aorta (ATA), aortic arch, upper-DTA, mid-DTA, and lower-DTA, and a distinct elastic material model (MAT_001) with Young's modulus E was assigned to each section. A Kroell-type frontal chest impact test at 4.3 m/s was simulated and the effective stress and strain were plotted vs time and compared with the original homogenous model (HM) with E = 8.87 MPa.

Results and Discussion:

There is an increase in E from proximal to distal sections. Lower-DTA is about 15% stiffer than the upper-DTA ($p<0.0001$). Moreover, in the circumferential direction, the medial side is significantly more compliant compared to other locations ($p<0.0001$).

The results of the GHBM simulation show the distribution of effective stress in IHM is more uniform than HM, while the peak stress in both cases remains at about 500 kPa. The peak stress in the isthmus region was increased by 47% in IHM. In the case of effective strain, the distribution becomes more uniform as well, however, the peaks were generally increased. In the isthmus region, the peak effective strain was increased by 152%.

Conclusions:

The proximal sections and the medial regions of aorta are more compliant and therefore experience higher strains under identical loading conditions. Our model predicts that the risk of injury in the isthmus region is significantly increased in the inhomogeneous model, which agrees with clinical observations. This suggests that it is important to implement the inhomogeneous biomechanical behavior of aorta in order to develop more reliable FE models of TAR.