DYNAMIC TENSILE CHARACTERIZATION OF PORCINE BRONCHI

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Introduction

The bronchial rupture was generally associated with high-energy impacts such as automobile collisions. The main bronchus was mostly injured compared to the trachea and lobar bronchi. Generally, these injuries are life-threatening; around 70 to 80% of the patients may die before arriving at the hospital [1]. However, these injuries can be predicted by performing high-impact simulations on a human body model. Literature on experimental studies on the bronchi is limited to the quasi-static regime. Therefore, it is crucial to determine the material properties of the bronchi at high strain rates. The current study provides insight into the dynamic behavior of bronchi at strain rates from 25 to 80 s^{-1}.

Methods

In the current study, the bronchi samples were sectioned from the porcine lung tissue obtained from the local butcher shop. The bronchi samples were obtained by peeling away the soft parenchyma tissue on its surface using a scalpel. The uniaxial tensile tests were performed on the bronchi sample using a hydraulic based dynamic test setup at 0.5 (25 s^{-1}), 1 (45 s^{-1}), and 2 (80 s^{-1}) m/s velocities. The load responses of the sample were recorded at 20 kHz using piezo load cells of 1 kN capacity and data acquisition system (Dewesoft Corporation, Slovenia). Using a high-speed camera, the deformation of the sample was recorded at 20,000 fps. The load-displacement data was synchronized using a laser displacement sensor, which triggers the high-speed camera and data acquisition system at the same time.

Results

The experimental data set consists of 15 tests conducted along the axial direction on porcine bronchi as shown in Fig. 1. The stress-strain curve (see Fig. 2) reflects a nonlinear strain rate dependency behavior of porcine bronchi. The engineering stress-strain curve was segmented into a toe and elastic region using a MATLAB bilinear curve fit. The RMS error between the experimental and the bilinear model are minimized using the unconstrained multivariable optimization.

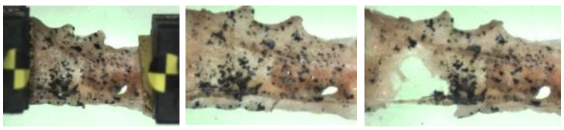

Figure 1: Sequence of tensile deformation of bronchi sample at a velocity of 2 m/s along the axial direction.

The bilinear material parameters shown in table 1, reveal that the toe and elastic modulus values increase with strain rate. The toe modulus values increase from 0.32 to 0.42 MPa, and the elastic modulus value increases from 3.42 to 8.3 MPa. At the same time, the toe strain value decreases from 0.28 to 0.22.

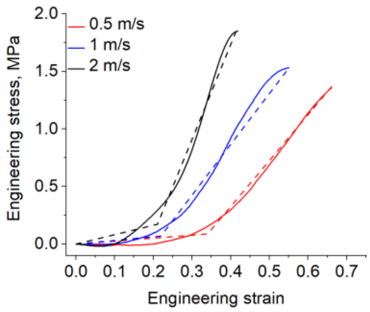

Figure 2: Sample engineering and bilinear stress strain curve of porcine bronchi.

Velocity, m/s	Toe modulus, MPa	Elastic modulus, MPa	Toe strain
0.5	0.32±0.1	3.42±0.8	0.28±0.06
1	0.38±0.1	5.36±1.1	0.26±0.07
2	0.42±0.4	8.30±1.5	0.22±0.04

Table 1: Bilinear material parameters of porcine bronchi.

Discussion

This study quantifies the variation of bilinear material properties of bronchi with strain rate. The nonlinear stress-strain behavior of bronchi is expected due to the presence of elastin and collagen. In the toe region, the elastin starts deforming, and the collagen uncrimp, whereas during the elastic region, the collagen fibers start deforming and tend to slide along the direction of loading. With the increase in strain rate, the total time available for the uncrimping and deformation of the tissue reduces, which results in the increase of modulus values and the decrease in toe strain. It should be noted that the current study was carried out only with the proximal bronchi. Studies by sattari et.al [2] show that the modulus of the proximal and distal bronchi shows significant variation.

References

1. van Roozendaal LM et al, J Thorac Dis, 10(9):5576-5583, 2018.
2. Sattari et al, Acta Biomater, 155:410-422, 2022.

Acknowledgements

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