High-rate viscoelastic shear properties of porcine skin, lung, and liver tissue

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Background

To model the response of the human body in high-rate injury events such as automotive crashes or behind armor blunt trauma, accurate material properties of biological tissues need to be determined. These tissues include not only the skeletal structure, but also soft tissues such as the skin and internal organs. In this study, the shear properties of these tissues are considered, and the viscoelastic nature that results in stress relaxation under loading. Viscoelastic characterization of shear in soft tissues often consists of oscillatory testing at small shear strain. However, shear strain during an injury event is usually large and often follows a ramp-like deformation.

Objective

This study is an investigation of high-rate viscoelastic shear properties of porcine skin, liver and lungs, providing an estimate for the shear properties of human skin, liver and lungs. A future determination of the properties for human tissues will allow for a quantitative evaluation of using porcine tissue as a surrogate. A comparison is made between these tissues and synthetic ballistic gelatin.

Methodology

Porcine lung, liver, ventral skin, and dorsal skin tissue was obtained from pigs shortly post-mortem and stored either at 4°C or at -18°C, to be thawed in 4°C later. Synthetic 10% and 20% gelatin (Clear Ballistics; Greenville, SC, USA) was heated and molded, and porcine tissue was cut into 10x10x10 mm cubes. Specimens were attached to two parallel plates using cyanoacrylate adhesive in either a transverse or parallel orientation. Specimens were tested in either room temperature (23.7°C +/- 1.9°C), or in a temperature chamber kept at body temperature (36-37°C). For each combination of tissue type, storage, orientation, and temperature, 5 specimens were tested. Each test consisted of high-rate shear (100 s^{-1}) ramps up to 10%, 15%, 30% and 40% shear strain, held for 100 s and repeated three times.

A quasi-linear viscoelastic model was developed and optimized with a linear elastic and exponential instantaneous elastic function, and a generalized Maxwell relaxation function. Three time constants were included in the model: 10 ms, 1s, and 100s, and a steady state relaxation coefficient.

Results and Conclusions

For tissues, the exponential elastic function provided better results than the linear elastic case, suggesting that the tissue is increasingly more resistant to shear at higher shear strain. The storage of the tissue and the temperature did not have a significant effect on the model parameters. The 20% synthetic gelatin had a linear instantaneous elastic function, but had otherwise overall similar relaxation behavior to the porcine skin in transverse. The shear modulus for the 10% gelatin was lower than for the 20% gelatin and skin, but higher than for the liver and the lungs.

In conclusion, porcine tissue exhibits shear relaxation behavior both at short and at long timescales, and that behavior differs for different tissues. Synthetic gelatin can potentially be an approximation for

porcine skin tissue in shear. These results allow for a future comparison to human tissues. Effects of tissue storage, temperature, and orientation are considered.