High rate mechanical behaviour and failure properties of aortic tissue

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Abstract

While traumatic aortic rupture (TAR) continues to be a major cause of fatality in motor vehicle accidents, its underlying mechanisms at the tissue level are not well understood. During accidents, aorta may undergo high-rate large deformations and therefore, the tissue mechanical properties obtained in the physiological range cannot accurately describe the tissue behavior in such conditions. Very few studies have investigated the mechanical behavior of aortic tissue in supra-physiological strain and strain-rates; none of them proposed a constitutive model suitable for the stress analysis that is relevant to TAR. The goal of this study was to investigate the rate dependence of failure properties of aortic tissue and characterize a constitutive model for the tissue based on high rate deformation tests.

A custom-made uniaxial extension test setup, capable of generating a wide range of strain rates, was utilized to characterize the mechanical properties of porcine aortic tissue up to failure at nominal strain rates of 5, 50 and 500 1/s. The high rates used in this study were one order of magnitude higher than previously reported results. Porcine aorta was used as a surrogate for young and healthy human aorta. Small dog bone shaped samples (10 mm x 5 mm gauge area) were excised along the longitudinal and circumferential directions from the peri-isthmus region. This region is the most frequently reported site of TAR. Samples were sprayed with a speckle pattern and the strain field was obtained using digital image correlation and the incompressibility assumption. Synchronized force and images were acquired at 14 ksamples/sec.

The aortic tissue was assumed to behave as an orthotropic quasilinear viscoelastic material with axes of material symmetry being along the circumferential and longitudinal directions. This assumption was verified by comparing the actual strain field with the ideal uniaxial deformation. The hyper elastic behavior of the tissue was characterized by fitting the Holzapfel-Gasser-Ogden two-fiber hyperelastic model to the experimental data in longitudinal and circumferential directions. A modified version of this model, as described by Volokoh (2007), was used to model the failure behavior of aorta. It was verified that the constitutive and failure parameters had significant rate dependence. This rate dependence was modeled with a 4-term Prony series for the reduced relaxation function.