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Circumferential variations of mechanical behavior of the porcine thoracic aorta during the inflation test

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ABSTRACT

We developed an extension-inflation experimental apparatus with a stereo vision system and a stress–strain analysis method to determine the regional mechanical properties of a blood vessel. Seven proximal descending thoracic aortas were investigated during the inflation test at a fixed longitudinal stretch ratio of 1.35 over a transmural pressure range from 1.33 to 21.33 kPa. Four circumferential regions of each aorta were designated as the anterior (A), left lateral (L), posterior (P), and right lateral (R) regions, and the inflation test was repeated for each region of the aortas. We used continuous functions to approximate the surfaces of the regional aortic wall in the reference configuration and the deformed configuration. Circumferential stretch and stress at the four circumferential regions of the aorta were computed. Circumferential stiffness, defined as the tangent of the stress–stretch curve, and physiological aortic stiffness, named pressure–strain elastic modulus, were also computed for each region. In the low pressure range, the stress increased linearly with increased stretch, but the mechanical response became progressively stiffer in the high-pressure range above a transition point. At a transmural pressure of 12.00 kPa, mean values of stiffness were 416 $\pm$ 104 kPa (A), 523 $\pm$ 99 kPa (L), 634 $\pm$ 91 kPa (P), and 489 $\pm$ 82 kPa (R). The stiffness of the posterior region was significantly higher than that of the anterior region, but no significant difference was found in pressure–strain elastic modulus.

1. Introduction

While it is well known that the mechanical properties of healthy blood vessels vary with location and age, their circumferential variations have received little attention. In biomechanical analysis of the aorta, it has been typically assumed that aortic thickness is constant and mechanical properties of the aorta are uniform in the circumferential direction. Recent biomedical imaging studies, however, reported that the circumferential deformation and wall distension of the aorta during the cardiac cycle were non-uniform (Draney et al., 2002, 2004; van Prehn et al., 2009). Few experimental studies have quantified the circumferential variations of the mechanical behavior of the aorta.

A variety of testing methods have been employed to characterize the mechanical properties of vascular tissue, including uniaxial and planar biaxial tests (Gundiah et al., 2007; Lally et al., 2004; Okamoto et al., 2002; Sokolis, 2007; Tremblay et al., 2010; Vande Geest et al., 2006; Zhou and Fung, 1997), ring tests (Guo and Kassab, 2004; Huang et al., 2006; Lillie and Gosline, 2007), and inflation tests (Blondel et al., 2001; Humphrey et al., 1993; Langewouters et al., 1984; Schulze-Bauer et al., 2002). It appears that the inflation test is the preferred test for estimating *in vivo* stress, because it closely reflects the motion of the aortic wall during the cardiac cycle. A video-based tracking technique with multiple markers embedded or affixed to the specimen is typically applied in order to enable monitoring of the large deformation of the vascular tissue (Everett et al., 2005; Hsu et al., 1995; Hu et al., 2007; Saravanan et al., 2006; Thubrikar et al., 1990; Zhang et al., 2002). In the traditional *ex vivo* inflation test, a blood vessel is commonly assumed to be a perfect cylindrical tube, and only its outer diameter change was measured during the test (Blondel et al., 2001; Langewouters et al., 1984; Schulze-Bauer et al., 2003; Valdez-Jasso et al., 2009), so that the spatial variation in the local mechanical properties of the vessel was not usually characterized. Recently, advances in three-dimensional (3D) imaging have allowed the use of 3D tracking systems to measure non-uniform deformation during the inflation test. In particular, Genovese (2009) introduced a new optical system with a concave conical mirror, which provides the full-field measurement of 3D deformation of an artery, and Avril et al. (2010) developed an inverse method to derive the material parameters based on the full-field experimental data. However, there is still a need for developing more analysis methods to utilize 3D spatial information in order

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