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Anisotropic AAA: Computational comparison between four and two fiber family material models

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ABSTRACT

Abdominal aortic aneurysm (AAA) is a cardiovascular disease with high incidence among elderly population. Biomechanical computational analyses can provide fundamental insights into AAA pathogenesis and clinical management, but modeling should be sufficiently accurate. Several constitutive models of the AAA wall are present in the literature, and some of them seem to well describe the experimental behavior of the aneurysmatic human aorta. In this work we compare a two (2FF) and a four (4FF) fiber families constitutive models of the AAA wall. Both these models satisfactorily fit literature data from biaxial tests on the aneurysmatic tissue. To investigate the peculiar characteristics of these models, we considered the problem of AAA inflation, and solved it by implementing the constitutive equations in a finite element code. A 20% axial stretch was imposed to the aneurysm ends, to simulate the physiological condition. Although fitted on the same dataset, the two material models lead to considerably different outcomes. In particular, adopting a 4FF strain energy function (SEF), an increase of the circumferential stress values can be observed, while higher axial stresses are recorded for the 2FF model. These differences can be attributed to the intrinsic characteristics of the SEFs and to the effective stress field, with respect to the one experienced in biaxial experimental tests on which the fitting is based. In fact the two SEFs appear similar within the region of the stress-strain experimental data, but become different outside it, as in case of aneurysms, due to the effects of the data extrapolation process. It is suggested that experimental data should be obtained for conditions similar to those of the application for which they are intended.

1. Introduction

Abdominal aortic aneurysms (AAAs) are permanent and irreversible dilatations that affect the aorta area. This disease is the 18th most common cause of death in all individuals and the 15th most common in individuals aged over 65 (Xu et al., 2010). From a clinical point of view, criticality of aneurysms is judged on the basis of their maximum bulge diameter, and typical cut-off values fall within the range 50–55 mm (Lederle et al., 2002). However, clinical experience reports that this is not a fail-safe criterion, since some AAA rupture at a smaller size (The Uk Small Aneurysm Trial Participants, 2002; Baxter et al., 2008), while others grow beyond such a range without rupturing (Hall et al., 2000). Moreover, several studies show that peak wall stress, calculated by Finite Element (FE) analyses, can be a more accurate indicator of AAA rupture risk (Fillinger et al., 2002, 2003; Venkatasubramaniam et al., 2004; Truijers et al., 2007; Vorp, 2007). For these reasons, the interest in AAA computational models has steadily increased in recent years. Regarding material models, findings that aorta becomes more anisotropic in presence of aneurysms have encouraged efforts in developing anisotropic constitutive models. Highly significant biaxial mechanical tests on both healthy and pathologic human aorta were conducted by Vande Geest et al. (2004, 2006). In recent years the same data were processed to fit fiber-based constitutive models previously proposed by Holzapfel et al. (2000), which have the advantage of evidencing the structural role of biological components. Several variations of the initial model were proposed (for further review see Holzapfel and Ogden, 2010), and some of them were specifically addressed to the AAA wall. For example Rodriguez and coworkers introduced a two fiber family (2FF) model with crimp and anisotropy parameters to assess wall stress distribution in idealized (Rodriguez et al., 2008) and patient-specific (Rodriguez et al., 2009) AAA geometries. In particular in Rodriguez et al. (2009) a comparison of an isotropic and two 2FF SEFs material model was presented. The results showed the extreme sensitivity of the aneurysm behavior to material formulation; however, the SEFs were not fitted on the same experimental dataset and consequently a specific distinction of the effects of the constitutive equations and of the fitting process (in terms of experimental dataset and working range) was not investigated.

Ferruzzi et al. (2011) finally fitted the biaxial data to the four fiber family (4FF) model initially presented in Baek et al. (2007). However, they did not apply the so obtained 4FF strain energy

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