Spatial orientation of collagen fibers in the abdominal aortic aneurysm's wall and its relation to wall mechanics

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1. Introduction

Ruptures of abdominal aortic aneurysms (AAAs) account for a large number of deaths, particularly in older men [20,36], and elective repair is indicated if the risk of aneurysm rupture exceeds the interventional risks. The clinically most frequently used indicator of the need for elective repair is the maximum diameter [1]. An AAA ruptures if the mechanical stress exceeds the local wall strength, hence alternative parameters to assess AAA rupture risk such as peak wall stress (PWS) [18,24,40,55] and peak wall rupture risk (PWRR) [24,40] are valuable. The computation of PWS and PWRR requires detailed knowledge of the constitutions of aneurysm tissues. Similar to other biological tissues, the mechanical properties of the aneurysm wall, such as strength, stiffness and toughness, depend to a large extent on the amount and spatial orientation of collagen [14,21].

Collagen is one of the most dominant structural proteins, and is critically involved in the gradual remodeling and weakening of the aneurysm wall [8]. Specifically, collagen fibrils are the basic building blocks of fibrous collagenous tissues [21], and their organization into suprafibrillar structures strongly influences the tissue's macroscopic mechanical properties. Consequently, biomechanical [29,39] studies invariably show that the mechanics of the arterial wall has a strong dependence on fibrillar collagens in media and adventitia. Collagen types I and III form about 90% of all collagen in the aortic wall, where the type I: type III ratio of about 74:26 remains unchanged between normal and aneurysmic walls [45,33]. While elastin almost disappears in large AAAs, the collagen content increases by about 50% compared to in the normal aorta [45,33]. Information of the collagen organization in the AAA wall permits a qualitative biomechanical understanding. However, the challenge is to relate it to engineering concepts and constitutive models, i.e. mathematical descriptions of biomechanical properties. Numerous constitutive models have been reported for soft biological tissues [16,17,25,30,37,41,44,52,53], some of which, denoted as