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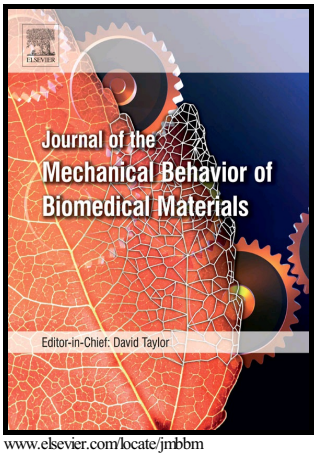

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Local mechanical properties of human ascending thoracic aneurysms

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Abstract

Ascending thoracic aortic aneurysms (ATAAs) are focal, asymmetric dilatations of the aortic wall which are prone to rupture. To identify potential rupture locations in advance, it is necessary to consider the inhomogeneity of the ATAA at the millimeter scale. Towards this end, we have developed a combined experimental and computational approach using bulge inflation tests, digital image correlation (DIC), and an inverse membrane approach to characterize the pointwise stress, strain, and hyperelastic properties of the ATAA. Using this approach, the pointwise hyperelastic material properties were identified on 10 human ATAA samples collected from patients undergoing elective surgery to replace their ATAAs with a graft. Our method was able to capture the varying levels of heterogeneity in the ATAA from regional to local. It was shown for the first time that the material properties in the ATAA are unmistakably heterogeneous at length scales between 1 mm and 1 cm, which are length scales where vascular tissue is typically treated as homogeneous. The distributions of the material properties for each patient were also examined to study the inter- and intra-patient variability. Large inter-subject variability was observed in the elastic properties.

Keywords: thoracic aneurysm, heterogeneous material properties, inverse elastostatic analysis, intra-patient variation, inter-patient variation, distribution of material properties

1. Introduction

Ascending thoracic aortic aneurysms (ATAAs) are focal, asymmetric dilatations of the aortic wall. A serious life-threatening pathology, the incidence of ATAAs is estimated at 10.4 per 100,000 people, suggesting that approximately 45,000 cases are diagnosed each year in Europe and the United States [8]. If an ATAA spontaneously ruptures, the result is almost invariably death [18]. Only two options exist for treating ATAAs: preemptive surgery or surveillance. Hence, the current objective in aneurysm care is to prevent rupture. Surgical repair is only indicated when the diameter of the aneurysm exceeds 5.5 cm. However, aneurysms with diameters greater than the surgical threshold may remain stable [1, 3, 18] and conversely, small aneurysms ($<$ 4.5 cm) do rupture [1, 4, 18]. Rupture is a localized phenomenon and to identify potential rupture locations in advance, one must consider the local mechanical conditions of the tissue.

ATAAs are evolving structures; both the geometry and the tissue properties change as the aneurysm grows. Existing studies showed a significant increase in matrix metalloproteinase activity [20] and apoptosis of smooth muscle cells in thoracic aneurysms [31]. Well-developed aneurysms typically have an attenuated media, fragmented elastin fibers, and abnormal collagen networks [17, 31]. Since the the local remodeling

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