Regional micro- and macro-structural properties of the aortic wall in ascending thoracic aortic aneurysms

Omid Ghorbani*†[1], Robert Matongo Persson[2], Vegard Skalstad Ellensen[2], Victorien Prot[1], Gerhard A. Holzapfel[1,3], and Bjørn Skallerud[1]

[1]Department of Structural Engineering, Norwegian University of Science and Technology (NTNU), Norway – Norway

[2]Department of Heart Disease, Haukeland University Hospital, Norway – Norway

[3]Institute of Biomechanics, Graz University of Technology, Austria – Austria

Abstract

Objectives. Ascending thoracic aortic aneurysms (ATAAs), defined by permanent enlargement of weakened aortic walls in the ascending thoracic aorta, exert region-specific effects on the aortic wall. Understanding these biomechanical variations is critical for developing risk criteria based on the material properties of the aortic wall. Previous studies mainly focused on limited cohorts (1). Patients with bicuspid aortic valve (BAV) are at a higher risk of developing ATAA, typically 10–15 years earlier than patients with tricuspid aortic valve, highlighting the significant impact on the incidence and progression of thoracic aneurysms (2). The current study investigates these effects in a cohort consisting primarily of BAV patients.

Method. Samples were collected from 10 ATAA patients and 3 healthy cadavers and sectioned into six regional specimens (_˜15 × 15 mm2): three from the major curvature (proximal to distal), one from the minor curvature, and two from the anterior and posterior regions. The specimens maintained their orientation to ensure circumferential (C) and longitudinal (L) alignment. Each specimen was subjected to quasi-static biaxial stretching at varying ratios (λlong:λcirc = {1:1, 1:0.5, 1:1.25, 1:0.75, 1:2}) with a linear rate of 1.5 mm/min. Planar deformation was assessed using planar digital image correlation at 2 Hz. After biaxial testing, the specimens were chemically fixed, dehydrated, and optically cleared. Collagen and elastin fiber distributions were imaged using two-photon excitation in a Leica confocal microscope with a scanned area of 465 × 465 μm2 at a resolution of 4.85 pixel/μm using line averaging to improve the signal-to-noise ratio. Z-stack images in the radial direction (R) were acquired in the C-L plane along with a single-depth image in the C-R plane to analyze fiber alignment with the circumference.

Results and Discussion. Fiber dispersion was quantified using von Mises distributions and combined with biaxial stress-strain data to create a multiscale material model of the aortic wall. The model is based on the fiber-reinforced strain-energy function of Holzapfel et al. (3) incorporating two dominant collagen fiber families in the C-L plane. High dispersion elastin fibers were modeled as part of the isotropic matrix to avoid overfitting.

*Speaker

†Corresponding author: omid.ghorbani@ntnu.no

Specimens from the main curvature (proximal, middle, distal) exhibited isotropic mechanical behavior. In contrast, regions on the minor curvature, anterior, and posterior showed anisotropic behavior with increased stiffness in the circumferential direction. These findings correspond to the observed collagen fiber patterns, where they were highly dispersed along the major curvature. In contrast, in other regions, collagens in the media reinforced the aortic wall circumferentially, while adventitial fibers showed dispersed and multi-directional patterns.

References

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