Investigating the biological and physical complexities of ascending thoracic aortic aneurysms

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SUMMARY

Introduction
Ascending thoracic aortic aneurysms (aTAAs) pose a significant threat, often remaining asymptomatic until a catastrophic rupture occurs. Traditionally, clinical assessment has relied on aneurysm size, guiding surgical recommendations. Nonetheless, the size-focused approach has its limitations, as over 50% of tears in the inner layer of the aorta (type-A dissections) occur at diameters below the recommended threshold. This highlights the need to redirect our attention toward evaluating factors beyond just diameter. This thesis endeavors to elucidate specific observable and measurable attributes of aneurysms in patients, providing a fresh perspective on aTAAs. The primary focus is on these measurable attributes, namely, geometry, kinematics, and constitutive modeling, while also addressing the existing gaps in our comprehension of the biomechanical characterization of aTAAs.

Geometry
In **Chapter 1** we conducted a literature review to assess the extent to which wall thickness is considered and measured in clinical research and practice. We concluded that there is a lack of a standard measurement technique amongst studies in assessing wall thickness. From a qualitative perspective, the variations in wall thickness measurements, observed in both aneurysmatic and normal aortas, do not exhibit a clear association with diameter. In **Chapter 2**, we focused on studying the variability in geometric characteristics of the ascending thoracic aorta within our patient population. To this end, we outlined a methodology for measuring the wall-to-lumen ratio (WLR) using *ex vivo* samples of ascending aortic aneurysm rings obtained during aortic repair surgeries. The reliability of our method was confirmed through a favorable Gage Repeatability and Reproducibility variance of less than 10%. The estimated WLR for the samples was on the order of magnitude of 0.2.

Kinematics
Regulation of the ascending thoracic aortic (ATA) tissue property is achieved through the detection of local biaxial strains by vascular smooth muscle cells. In **Chapter 3**, we evaluated a novel intra-operative video-based method to measure ATA local biaxial strains on a group of 30 patients. The precision of our measurements was notably high, with coefficients of variation for biaxial strains consistently remaining below 20%. The magnitude of the strains we recorded, were within the range of 0.02 to 0.05. In **Chapter 4**, we extended our study group to 67 patients and applied the method developed in Chapter 3 to this larger population. We detected a regional circumferential strain difference, while no regional strain difference was observed for axial strains. Globally, axial and circumferential strains decreased with increase in age and diameter, while they increased with increase in pulse pressure.

Constitutive modeling

In **Chapter 5**, we developed an algorithm, as a solution to an otherwise arduous procedure, to estimate mechanical properties of the ascending thoracic aorta non-invasively while considering the pre-stresses. With this method, we achieved estimates of true mechanical properties with an accuracy ranging from 98% to 99%. In **Chapter 6**, we conducted an *in silico* investigation on the biomechanical response of the ascending aorta, taking into account the insights gained from Chapters 3 and 4 and the importance of boundary conditions discussed in Chapter 5. The results from Chapter 6 underscore the significance of considering dynamically varying axial stretches while estimating *in vivo* biomechanical properties of the ascending thoracic aorta.

Conclusion

In summary, the techniques developed and the results obtained in this thesis are valuable not only for comprehending the biomechanical aspects of the ascending thoracic aorta at a specific time point but also for examining the alterations that occur in aortic tissue over time, including the effects of growth and remodeling that can lead to aneurysm formation.