Hemodynamics of a Patient-Specific Compliant Thoracic Aorta Model in non-Newtonian Pulsatile Flow

Benedikt Johanning-Meiners[*], Esther Lagemann[†], Steven Brunton[†], Michael Klaas[*]

Cardiovascular diseases are among the leading causes of mortality world-wide. Given their close association with the flow conditions in elastic blood vessels, effective disease prevention and personalized treatment require a deeper understanding of the complex flow dynamics within the cardiovascular system. Unfortunately, the resolution of *in-vivo* 4D flow measurements based on Magnetic Resonance Imaging (MRI) is too coarse to provide sufficient physical insight. Therefore, *in-vitro* experimental studies focusing on the fluid-structure interaction, the non-Newtonian fluid behavior, and the compliance of blood vessels in pulsatile flows are crucial for deriving comprehensive insight into *in-vivo* human hemodynamics.
In this study, high-resolution experimental measurements are conducted on a subject-specific thoracic aorta model, which is derived from clinical data of a healthy patient[1]. Using a novel casting technique, the high-precision elastic model allows to investigate the effect of the fluid-structure interaction and the vessel compliance. The model is integrated into a closed-loop that closely mimics the physiological conditions in the human body. A non-Newtonian fluid specifically designed to replicate the properties of human blood flow[2] and a pulsatile flow representative of the true patient-specific cardiac waveform allow to study the entire complexity of subject's hemodynamics. Hence, 3D Particle Tracking Velocimetry (PTV) measurements were conducted using the Shake-the-Box algorithm for Reynolds numbers and Womersley numbers in the range of [1000, 2000] and [14, 17], respectively.
Moreover, we leverage our high-resolution experimental dataset to enrich complementary low-resolution 4D MRI flow data. Based on a physics-informed spatio-temporal diffusion model, we are able to significantly enhance the spatial and temporal resolution of the low-resolution MRI flow data, providing a novel framework to increase the flow field information that can be extracted from clinical measurements.

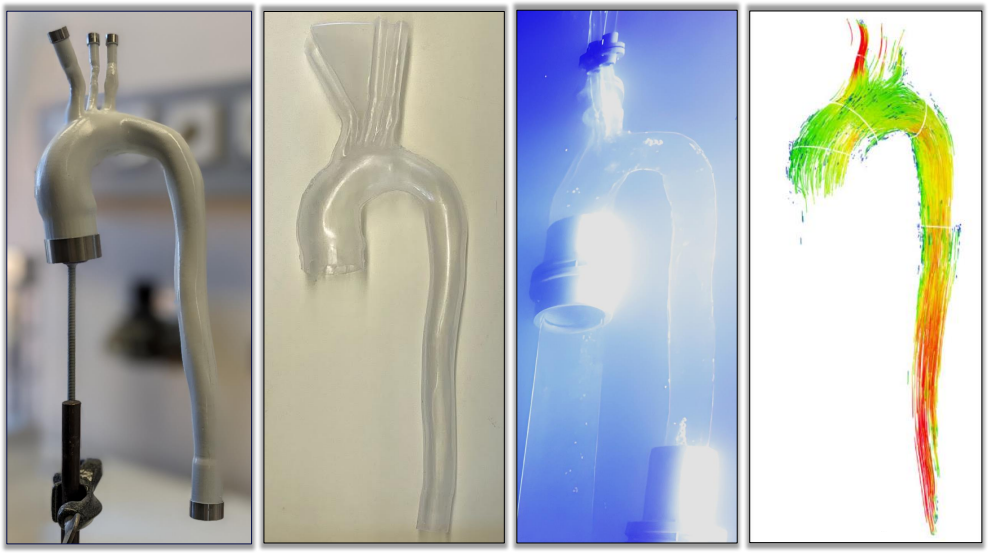

Figure 1: **Workflow for deriving patient-specific hemodynamics from *in-vitro* experiments**. From left to right: A 3D-printed wax model is generated based on clinical data. Subsequently, a compliant model is cast using RTV615, with a Young's modulus comparable to that of a human aorta. This model is then embedded in a closed-loop circuit that generates the physiological conditions of pulsatile human blood flow. Utilizing 3D Particle-Tracking Velocimetry, time-resolved 3D flow fields are obtained.

[*]Institute of Aerodynamics and Chair of Fluid Mechanics, RWTH Aachen University, Wüllnerstraße 5a, 52062 Aachen, Germany
[†]AI Institute in Dynamic Systems, Department of Mechanical Engineering, University of Washington, Seattle, United States
[1]Zimmermann et al., *Scientific Reports* **11:6703** (2021)
[2]Dörner et al., *European Journal of Mechanics/B Fluids* **87**, 180–195 (2021)