Experimental PIV Analysis of Hemodynamic Flow in the Thoracic Aorta with Patient-Specific Boundary Conditions

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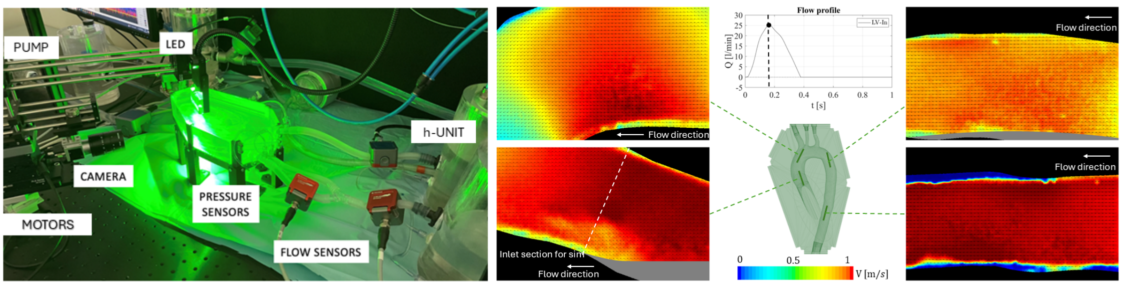
Cardiovascular flow fields have been increasingly studied in recent years through Computational Fluid Dynamics (CFD) [1]. CFD results are often validated against *in-vivo* MRI data, which suffer from low resolution both in space and time. Other sources of uncertainties are present when comparing CFD results and *in-vivo* data, as, e.g., the unknown bio-mechanical properties of the vessel walls. Therefore, there is a need for validation of simulations against *in-vitro* experimental setups, which allow for controlled conditions that provide reliable data for comparison.

In the present work, we conducted experiments in the mock circulatory loop described in Vignali et al.[2]. Specifically, we analyze hemodynamic flow in a 3D-printed patient-specific aorta phantom using Particle Image Velocimetry (PIV). A hollow 3D CAD model, reproducing the negative of a patient-specific thoracic aorta, is used for the analysis. The box containing the phantom is designed as a polygonal shape, enabling the investigation of four different aortic sections (ascending aorta, aortic arch, descending aorta, and descending arch). For accurate PIV measurements, the phantom is fabricated from Sylgard 184 silicone. Specifically, the phantom cavity is created using an ABS core, which is 3D printed with Fused Deposition Modelling (FDM) technology, surrounded by Sylgard to obtain a rigid wall condition. The manufactured phantom is then inserted into the mock circulatory loop, shown in Fig. 1a, where the patient-specific inlet flow-rate profile is imposed through a highly-versatile and accurate piston pump[2] and its distribution through the outlets is governed by hybrid-UNIT (h-UNIT) pressurized chambers[2] emulating the 3-element Windkessel model often used as outflow boundary condition in CFD simulations. The PIV setup consists of: (i) a LED for flow and particle illumination (10 m hollow glass spheres), (ii) a camera for image acquisition, and (iii) a working fluid (51% water, 31% glycerol, 18% urea by mass) designed to match the density and viscosity of blood, as well as the refractive index (RI) of Sylgard.

As an example of the results, we present the PIV data for the four investigated central planes shown in Fig. 1b. We focus on the systolic peak of the cardiac cycle, presenting the phase-averaged velocity flow field over ten cardiac cycles. The vectors represent the in-plane velocity direction, and the colour scale indicates the velocity magnitude. The phase-averaged velocity standard deviation is less than 0.2 m/s.

This work provides a PIV database for a patient-specific 3D-printed aorta phantom with well defined inflow, outflow and wall boundary conditions, inserted into a mock circulatory loop, which can be used for the validation and benchmarking of numerical simulations. We are currently simulating the flow with different CFD codes. The results will be shown and compared to the experiments in the final presentation.



(a) (b)

Figure 1: (a) PIV set-up and (b) example of PIV results at the systolic peak

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[1] Mariotti et al., *CAF* **230**, 105123 (2021)
[2] Vignali et al., *ASAIO Journal* **68(10)**, 1272-1281 (2022)