UCL-Royal Free AVM Research Programme:

Engineering report 2022

Background

Congenital arteriovenous malformation (AVM) is an inborn disorder in which the blood vessels within a specific area of the body are incorrectly formed, resulting in multiple abnormal communications between the arteries and veins. In AVMs, capillaries are bypassed by larger channels connecting directly the arteries with the veins; this phenomenon is known as shunting. The channels linking the arteries with the veins are named the nidus. The shunt causes a rise in the blood flow and pressure in the venous side; over time this can damage and cause ischaemia to the tissue in the surrounding areas and leads to an increase in heart workload. Some of the consequences are disfiguration, pain, swelling, and life-threatening bleeding and organ failure. AVMs affect all age groups but there are no quantitative tools to objectively assess and treat AVMs. Therefore, patients may be subjected to numerous potentially risky interventions with suboptimal outcome.

We aim to develop an engineering framework to personalize the management of AVMs by combining medical images, computational modelling (CFD) and in vitro tools to quantify the haemodynamics of AVM in pre- and post-intervention (embolosclerotherapy) configurations. Our previous work (Franzetti et al., 2022) has demonstrated the feasibility of patient-specific computational framework for the embolosclerotherapy of an extracranial AVM assuming steady blood flow; the present work aims to introduce additional patient-specific features to enhance the realism and create more reliable simulations.

Recent findings

The blood flow in AVMs is difficult to assess without invasive techniques such as digital subtraction angiographic (DSA) imaging. These techniques are qualitative. By means of 3D patient-specific flow modelling we aimed to elucidate the haemodynamics in this complex pathology and provide quantitative metrics for interventional planning. A patient-specific geometry from an extracranial Yakes Type III AVM was extracted by segmenting head and neck CT scans. CFD simulations were performed considering an inlet periodic waveform mimicking the nature of the cardiovascular flows. In the

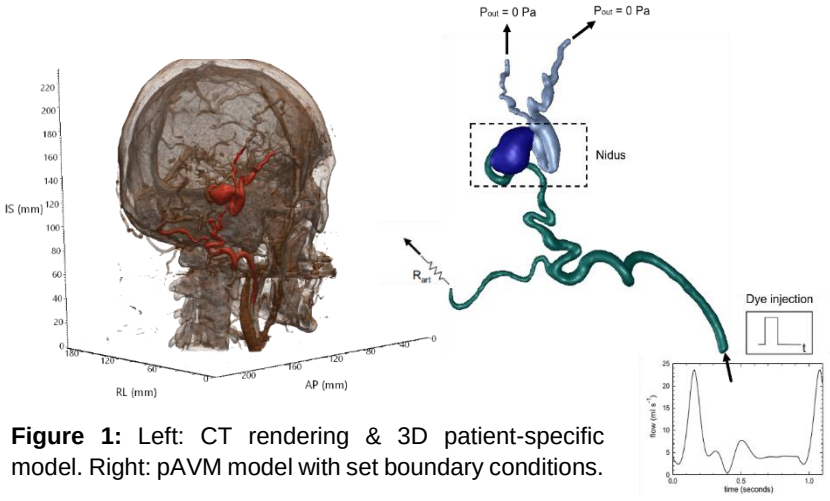


Figure 1: Left: CT rendering & 3D patient-specific model. Right: pAVM model with set boundary conditions.

absence of ultrasound blood flow measurements in the artery feeding the malformation, an inlet velocity profile, obtained from the literature and scaled based on DSA based flow estimations was implemented to further advance the previously developed framework (**Figure 1**). The nidus structure was idealized as a homogenous porous medium and the DSA contrast agent simulated as a passive scalar whose transport is described by the convection-diffusion equation.A comparison between the *in vivo* DSA images and the simulated blood flow contrast agent transport under steady and unsteady flow conditions has been carried out and shown in **Figure 2 A**. The results reveal a good agreement between patient DSA images and simulations with minimal differences between steady and unsteady flow results. A quantitative comparison, selecting 6 regions of interest within the patient flow domain, has been carried out to further elucidate the differences between computational simulations and medical images, shown in **Figure 2 B**. It can be seen that both models can capture the contrast agent distribution at 4 of the 6 chosen locations: the outlet and inlet of the feeding artery (**Figure 2 B1 & B2**) as well as the nidus and the inlet of the nidus (**Figure 2 B5 & B6**). However, the computations fail to accurately capture the *in vivo* contrast agent distribution in the draining veins (**Figure 2 B3 & B4**). Further investigation is required to fully understand the source of these discrepancies and further validate the computational modelling. The resolution of the medical images used for reconstruction, the small scales of the vessels, the temporal resolution of DSA as well as the lack of blood flow measurement might contribute to the observed differences.

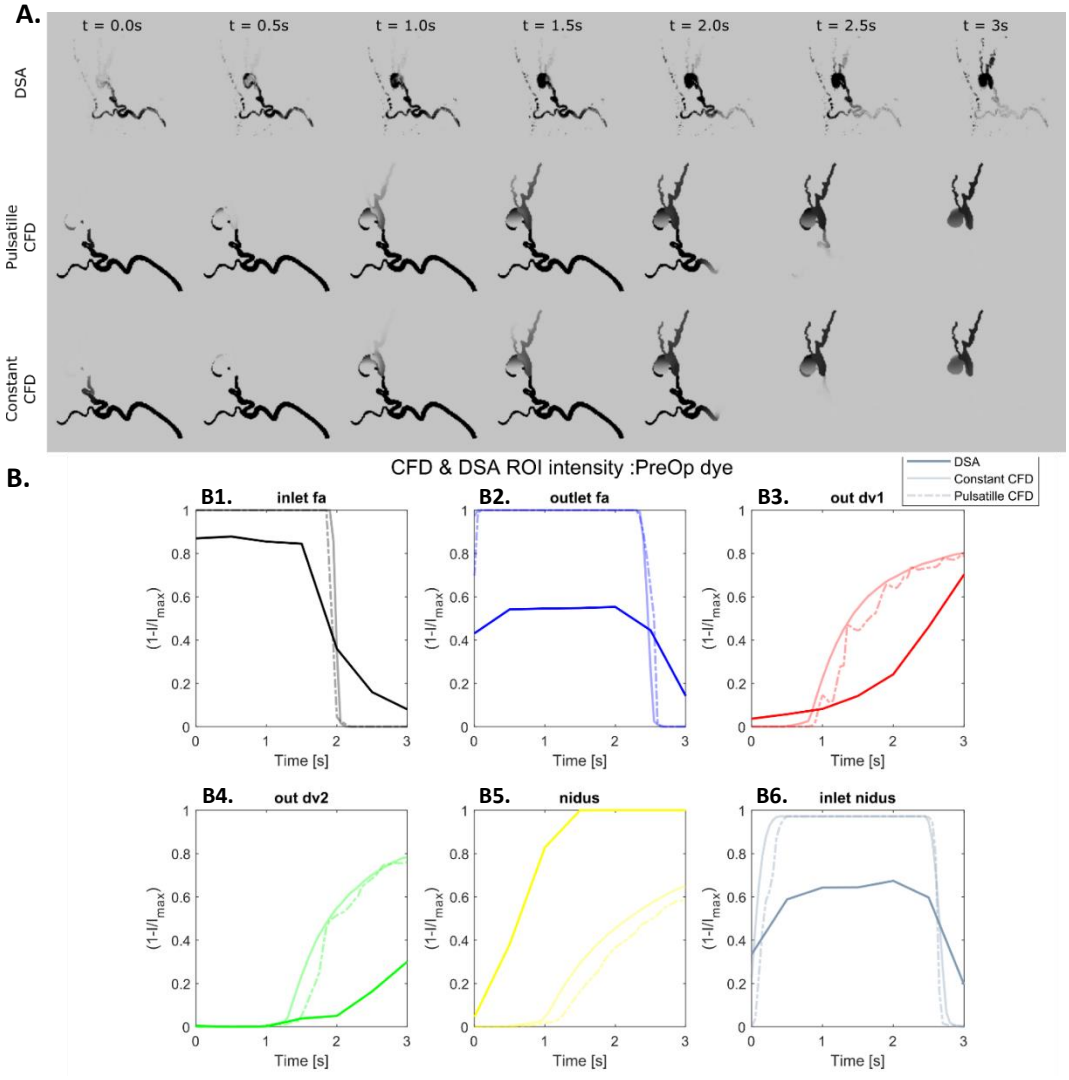
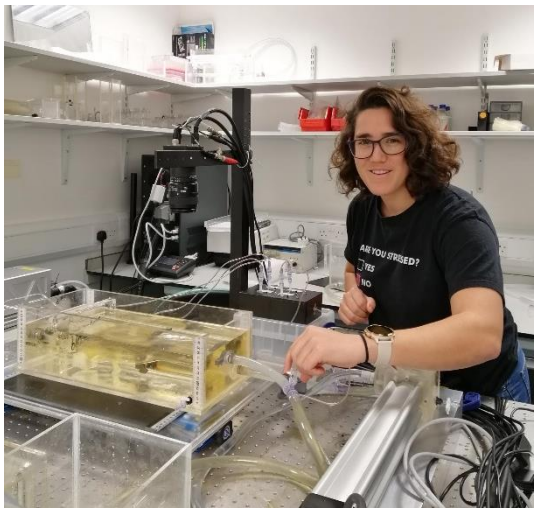


Figure 2: DSA and CFD dye (Contrast Agent) distribution quantitative comparison in selected regions of interest (ROI) at critical points for the pre intervention (PreOp) scenario.

Other news and updates



Aloma Blanch Granada, a former Fulbright scholar, has joined the group as a PhD student (September 2021) to develop the engineering-based tools for the treatment of peripheral arteriovenous malformations in collaboration with experimentalists in the UCL Wellcome / EPSRC Centre for Interventional and Surgical Sciences and the peripheral AVM team at Royal Free Hospital.

Future work

Patient data collected at the Royal Free Hospital with the support of the Butterfly AVM Charity form the basis of ongoing work.

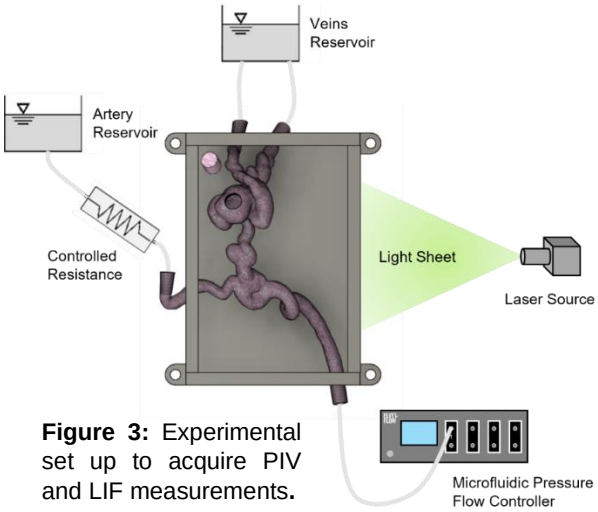


Figure 3: Experimental set up to acquire PIV and LIF measurements.

The project is still in its early stages, focusing on the presented AVM case whose features could be reconstructed from available medical images. To validate the results introduced above, *in vitro* 3D phantom experiments using advanced optical diagnostic techniques, such as Particle Image Velocimetry (PIV) and Laser Induced Fluorescence (LIF) are being carried out. **Figure 3** illustrates the experimental set up implemented. These advanced techniques will allow us to capture the velocity field as well as the distribution of the contrast agent in different parts of the domain. These will be compared quantitatively to the results obtained with CFD simulations and used for validation.

In addition to the patient presented above, we aim to include more patients with different Yakes types AVMs (Yakes & Baumgartner, 2014) to characterize and analyse their respective flows. We are currently working on a case of a facial AVM, where the nidus naturally thrombosed. The data collected from the patient during the past two years, allow us to recreate three different geometries, depicting three different stages during the process where the nidus naturally thrombosed. **Figure 4** illustrates the pre-thrombosis stage. Implementing 3D patient-specific modelling to the three stages will allow us to evaluate hemodynamic markers such as wall shear stress (WSS), oscillatory shear index (OSI) and the relative residency time (RRT). Those markers are linked to thrombosis (Kroll et al., 1996).

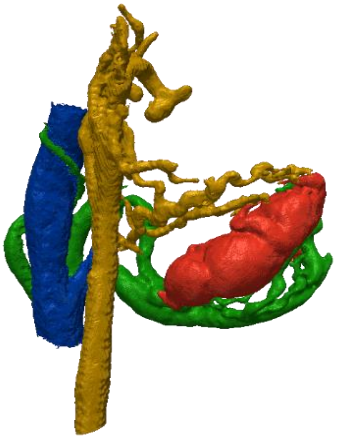


Figure 4: 3D segmentation of the facial AVM at pre-thrombosis stage.

Furthermore, we plan to explore the fusion of MR images and computational algorithms by applying super image resolution methods and machine learning to improve clinical MR images of AVMs obtained from the University of Bern to make them suitable for pAVM angioarchitecture extraction.

In terms of scientific dissemination, we plan to submit an abstract from this work to the 28th Congress of European Society of Biomechanics (ESBiomech2023) that will be held in Maastricht, the Netherlands, the 9-12 July 2023.

We would like to thank the Butterfly AVM Charity for their invaluable support in the development of the research and early career research training (Aloma Blanch Granada). This project is a unique opportunity to apply engineering tools to personalize interventions for this complex pathology and to allow Aloma to develop as a researcher, producing engineering tools to help treat AVMs and engage in patient driven research.

References

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