PERSPECTIVE

Computational fluid dynamics: simulation studies in cerebral aneurysms

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Aneurysms are outpouchings from blood vessels and can occur in any blood vessel in the body. Cerebral aneurysms are potentially lethal lesions and have the propensity to rupture, leading to subarachnoid haemorrhage, which can cause instantaneous death (figure 1). They are managed either by open surgical procedures, which include surgical clipping and cerebrovascular bypass procedures, or by using endovascular techniques such as coiling or flow diverter placement.

With the increasing number of unruptured intracranial aneurysms being diagnosed, there is a growing demand to understand the rupture risk of aneurysms. Rupture risk predictions rely on pooled statistical data and parameters such as age, size and location of the aneurysm, whereas patient-specific hemodynamic factors are seldom considered. However, smaller aneurysms are also known to rupture. Decisions are often intuitive and based on reasonable logic. Further, the elective management of unruptured aneurysms, either surgical or endovascular, is not risk-free. Hence, it is imperative to shift the focus of predicting the rupture

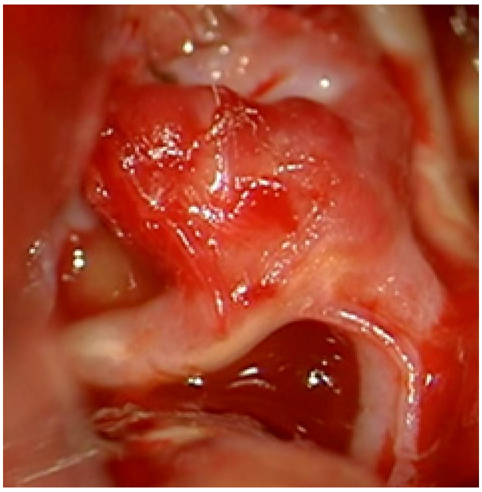

Fig 1: An anterior communicating artery aneurysm exposed during surgery

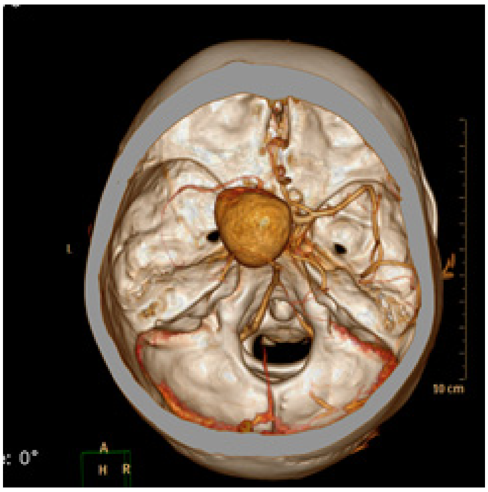

Fig 2: Computed Tomography Angiogram showing a giant cerebral aneurysm

risk of aneurysm from using pooled cohort data to the hemodynamic characteristics of the individual patient's aneurysm in order to improve the accuracy of risk prediction and reduce patient morbidity and mortality with optimal and timely intervention.

The management of complex aneurysms of the brain often allows only a one-time opportunity for surgical management. Computational simulation of aneurysmal blood flow allows for testing surgical interventions in the "lab" before em-

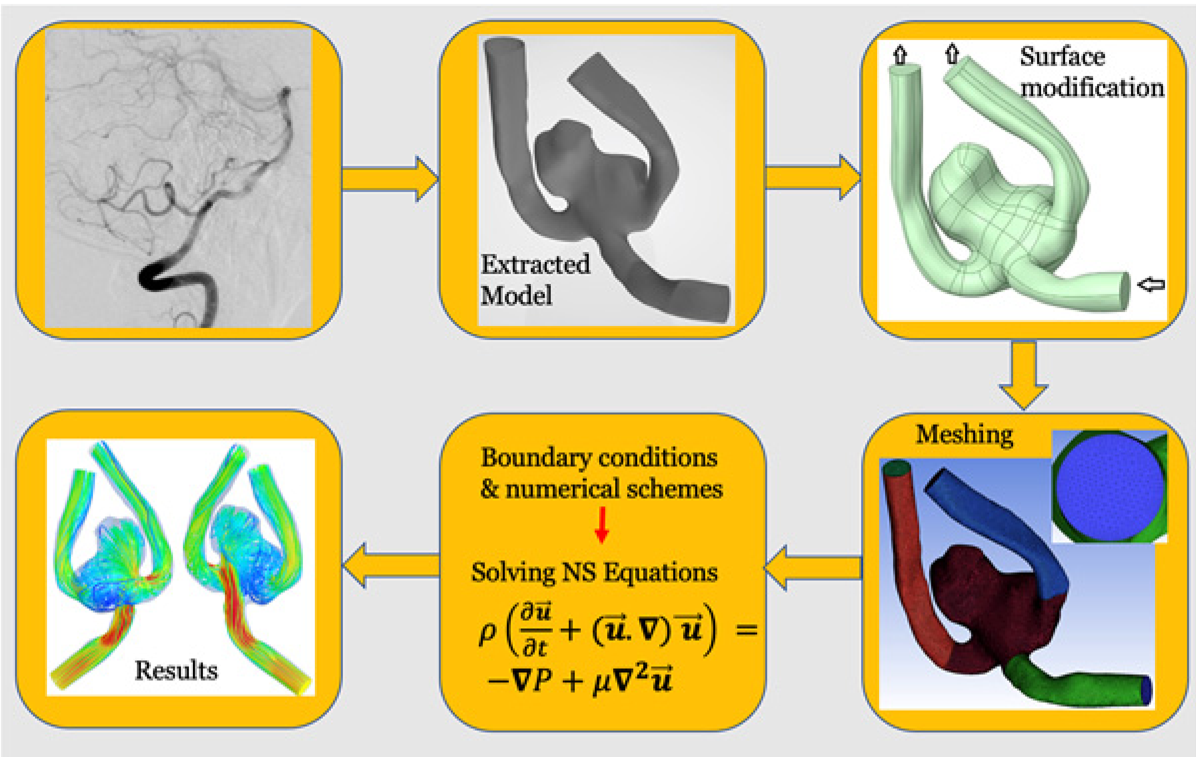

Fig 3: The CFD workflow: Angiography images are extracted and processed before subjecting to computational simulation to obtain results

barking on the actual surgical management in the operation theatre. Simulating blood flow in aneurysms is possible using computational fluid dynamics (CFD) amalgamating modern imaging techniques, advanced software and super-computing facilities. Angiography images of aneurysms are obtained, and the region of interest constituting the aneurysm and its inlet and outlet blood vessels are extracted. This three-dimensional geometrical model is subjected to blood flow analysis using computational software by feeding in near-realistic patient-specific physiological parameters such as blood flow velocity and viscosity (figure 3). Super-computing facilities reduce the computational time needed for such simulations.

Typical CFD results include hemodynamic parameters such as wall shear stress (WSS), Relative Residence Time (RRT), Oscillatory shear index (OSI), velocity profiles, pressure plots and flow streamlines (figure 4).

Wall shear stress is the tangential shear force flowing blood exerts on the vessel wall. Both low and high WSS have been proven to increase the risk of aneurysm initiation and rupture. The oscillatory shear index describes the disturbance and turbulence of blood flow within the aneurysm and ranges from 0 (steady flow) to 0.5 (intense oscillation). High OSI within the dome of an aneurysm is associated with increased rupture potential. Such results allow the clinician to understand the blood flow characteristics of aneurysms. These parameters could reinforce the knowledge of rupture risk prediction and clinical decisions on management. Combined with clinical and radiological data, a holistic approach to rupture risk prediction can also be performed using machine learning techniques. Flow streamlines offer a colourful visualisation of blood flow paths through the aneurysm, delineating zones of impingement, turbulence, eddies and flow velocity.

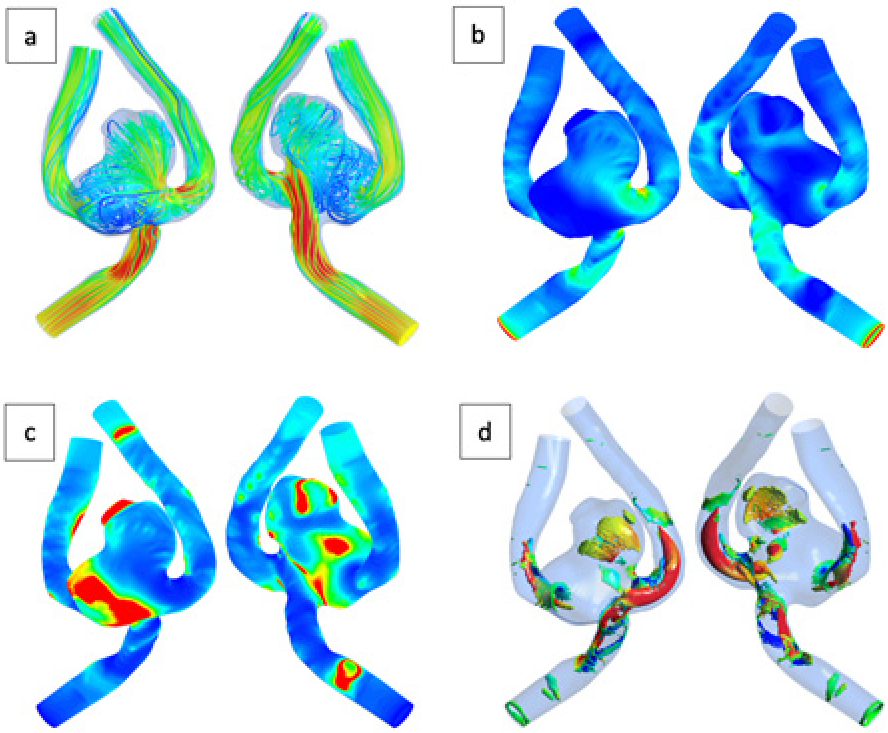

Fig 4: The CFD results: a. Velocity streamlines, b. Wall Shear Stress (WSS), c. Relative Residence Time (RRT), d. Turbulence modelling

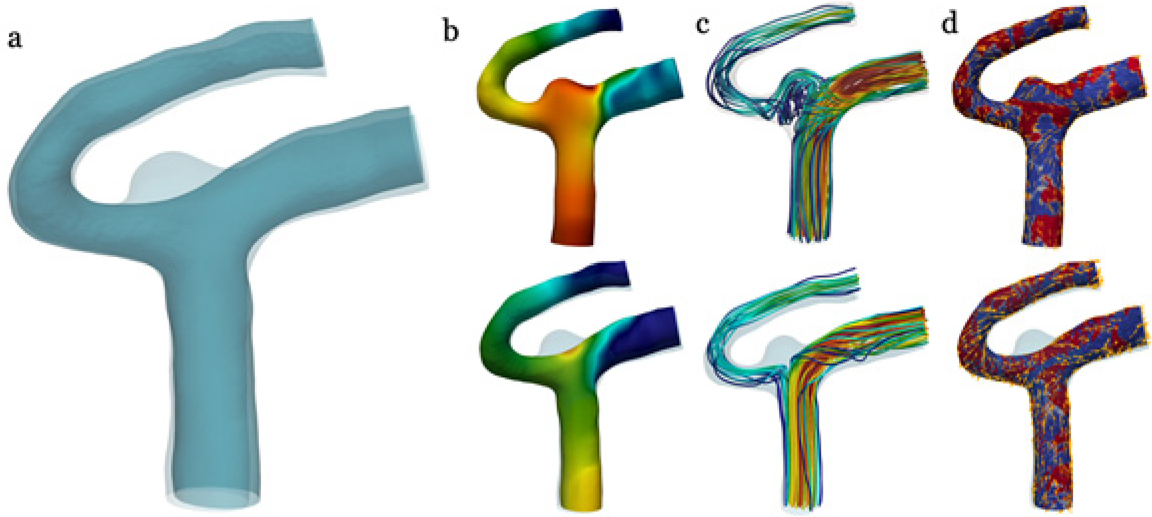

Fig 5: (a) A bifurcation aneurysm has been erased computationally to reconstruct the native blood vessel. Simulations are performed with and without the aneurysm to generate hemodynamic parameters: (b) Mean Pressure, (c) Velocity streamlines and (d) Wall shear stress divergence map

Radiological imaging gives static pictographs of the current status of aneurysms, and deciphering their origin and evolution is clinically challenging. It is possible to erase aneurysms from their parent vessel computationally. This allows for understanding the natural history of initiation and formation of an aneurysm and the reasons behind the occurrence of aneurysms in that blood vessel. Further, the evolution stages of aneurysms can be studied by running simulations. Such studies offer crucial insights into the hemodynamic factors that are responsible for the evolution of aneurysms (figure 5).

Currently, CFD simulations are not used in clinical decision-making protocols. This stems from the fear that the results are far from reality due to various assumptions in the CFD studies. Researchers are consistently trying to produce patient-specific simulations for better acceptance among clinicians.