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Abstract Title: Is CFD Misleading Us About the Nature of Wall Shear Stresses in Cerebral Aneurysms?

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Abstract:

Computational fluid dynamics (CFD) simulations are increasingly being used to model cerebral aneurysm hemodynamics and wall shear stress (WSS) in order to infer aneurysm wall strength and therefore risk of rupture. Numerous recent computational studies have been successful in retrospectively classifying aneurysms according to their rupture status, but the link between the proposed hemodynamic indices and the precise mechanisms leading to rupture remains unclear. One presumption common to virtually all of these CFD studies is that blood flow inside an aneurysm is laminar and stable, even though it is well known that many aneurysms produce sounds or bruits with energy peaks at hundreds of Hz. Clinicians have reported this invasively and non-invasively, and turbulence has been shown to occur in intracranial aneurysms in several experiments. These phenomena seem have raised little interest in the computational biomechanics community, and there is therefore a gap between the clinically reported frequencies and the resolution at which the simulations are performed. We have previously shown, using direct numerical simulation of pulsatile flow in two patient-specific middle cerebral artery (MCA) aneurysms, that transitional flow was present, leading to strong wall shear stress gradients. More recently, we have demonstrated the presence of unstable flow patterns in 5 of 12 MCA aneurysm cases simulated under high resolution, transient steady flow conditions. These findings would suggest that in many cases the aneurysmal wall may be subject to more violent forces than have been predicted by the vast majority of CFD model studies. To illustrate this, we carried out transient steady flow simulations for the two MCA cases we had previously simulated with DNS, using a first order accurate solver with roughly 600,000 linear tetrahedral and boundary layer elements and 10 msec temporal resolution, and a second order solver with the same number of elements (i.e. more than double the spatial resolution) and 0.03 msec temporal resolution. The latter simulations exhibited strong velocity and WSS fluctuations, as anticipated from the previous DNS studies, whereas the first order simulations stabilized quickly. These preliminary head-to-head comparisons are currently being extended to more cases, and under pulsatile flow conditions. In summary, the presumption of laminar, stable flow underlying most CFD models of cerebral aneurysms may be a self-fulfilling prophecy that leads to a misinterpretation of the biomechanical forces at play in aneurysm progression and rupture.