Mechanobiology of Intracranial Aneurysm Evolution: Modelling, Reflections & Directions

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Abstract

Intracranial aneurysms (IAs) are a disease of the brain vasculature. They appear as a sac-like out-pouching of a part of the arterial wall, inflated by the pressure of the blood that fills them. They are relatively common and affect up to 5% of the adult population. Most remain asymptomatic; however, there is a small but inherent risk of rupture. If rupture occurs there is a 30% to 50% chance of fatality. Consequently, if an IA is detected, clinical intervention may be deemed appropriate. However, interventional procedures are not without risk to the patient. Given the relatively low risk of rupture it would be desirable to be able to identify those aneurysms most at risk of such an episode. This would assist clinical diagnostic procedures and avoid the potentially undesirable consequences of an unnecessary operation. It is envisaged that computational models of IA evolution may help in achieving this aim [1].

Most IA evolutions models to date have focused on modelling the microstructural changes to the arterial wall that give rise to the enlargement. To move forward, there is a need for a new class of models which explicitly represent the vascular cells and the regulatory signaling pathways of the arterial wall [2]. This may assist in stratifying aneurysms which are chemo-mechano-biologically stable from those that are likely to enlarge/rupture.

Aparicio et al [1] recently proposed a novel Chemo-Mechano-Biological (CMB) model of cell–driven arterial growth and remodelling (G&R) in response to mechanical and biochemical stimuli. Briefly, a conceptual 1D model of IA evolution that models aneurysms as enlarging nonlinear elastic cylindrical/spherical membranes [2] is coupled to a signalling pathways model capturing Transforming Growth Factor β regulation of fibroblast activation and matrix G&R [3]. In addition, we model the changing mechanical role of the adventitia, i.e. from protective

sheath to a main load bearer; this is achieved by introducing a collagen attachment stretch distribution that can adapt. We overview this modelling approach and its integration into a Fluid–Solid–Growth (FSG) computational framework [4]. An illustrative application of evolution of a saccular IA on an internal carotid artery is considered. We conclude with a critique of the modelling framework and outline directions for future research.

References

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