Improved diagnosis of cerebral vasospasm through a sensitivity analysis of a 1D cerebral circulation model

A. Melis[1], F. Moura[2], I. Larrabide[3], R.H. Clayton[4], A.P. Narata[5], A. Marzo[1]

1. Department of Mechanical Engineering, The University of Sheffield, UK
2. Engineering, Modeling and Applied Social Sciences Center, Federal University of ABC, Brazil
3. Pladema-CONICET-UNICEN, Tandil, Argentina
4. Department of Computer Science, The University of Sheffield, UK
5. University Hospital of Tours, UMR “Imagerie et Cervau”, Tours, France

INSIGNEO
Institute for *in silico* Medicine

Background

Cerebral vasospasm (CVS) is the progressive narrowing of intracranial arteries following brain hæmorrhage [1]. Currently, its diagnosis relies on monitoring mean blood velocity with transcranial Doppler (TCD). Using velocity as CVS *biomarker* is effective when TCD measurements are performed on the narrowing vessel. When CVS affects the peripheral vasculature, the velocity biomarker becomes less effective and CVS is not detected until the condition becomes severe.

Methods

A mechanistic 1D model of the cerebral circulation was developed to study the influence of vessel narrowing on pulse waveforms that propagate through our system (Figure 1). A sensitivity analysis empowered by Gaussian process (GP) emulation [2] was performed to identify those waveform features that are most sensitive to vessel narrowing indicative of CVS. The use of GP emulators reduced the computational cost of the analysis by 95% compared to a full Monte Carlo analysis.

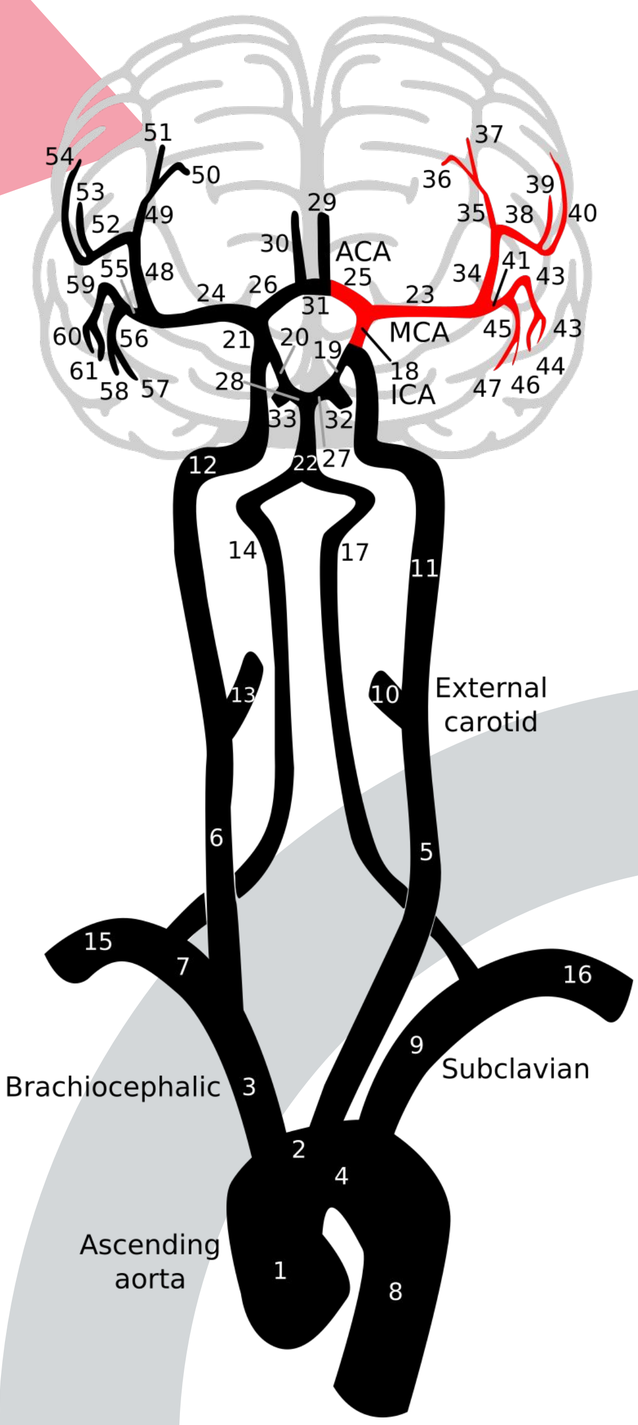

Figure 1. Diagram of the whole cerebral circulation and, in red, the part of the network affected by CVS.

Results

A CVS occurring at the measurement location caused an increase (more than 150%) of the mean velocity biomarker (Fig.2). However, when CVS affects peripheral vessels and the measurement point is proximal, the mean velocity biomarker was only marginally affected by the vessel lumen reduction. Instead, the minimum gradient of the velocity waveform was sensitive to CVS in distal arteries. Increase (up to 150%) of this biomarker occurred for all the CVS configurations tested.

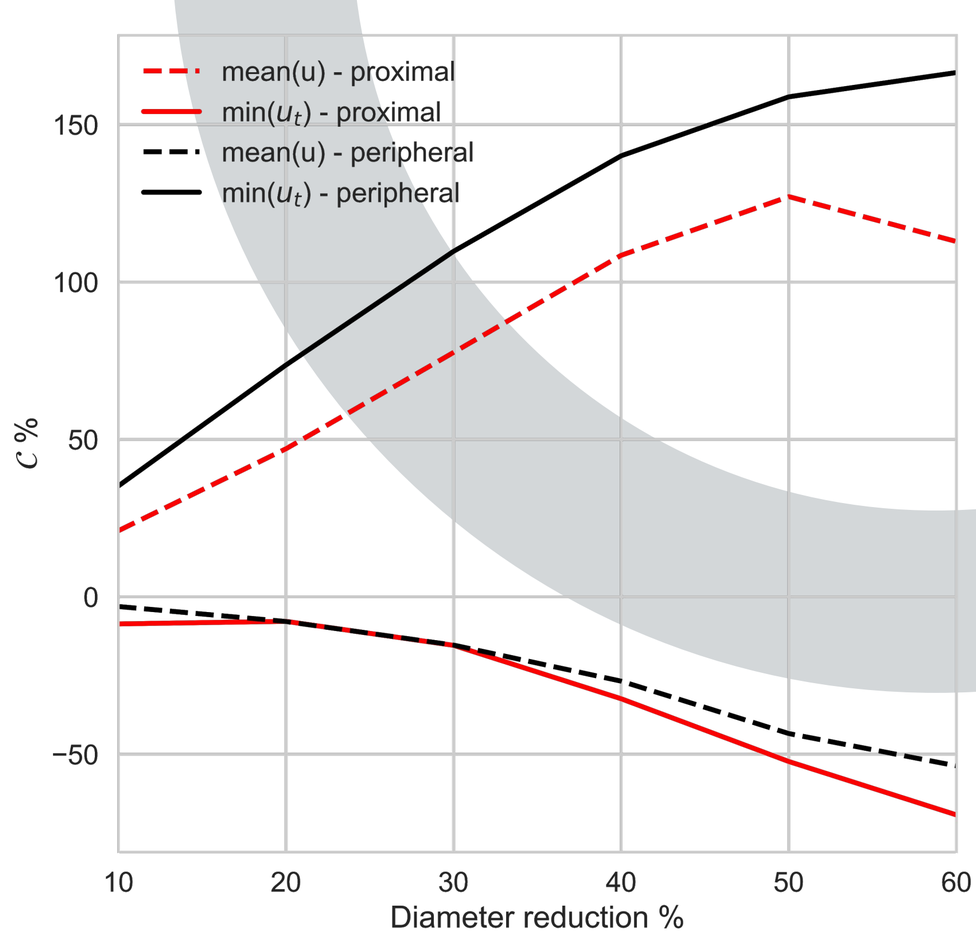

Figure 2. (a) Proximal and (b) distal CVS simulation results in terms of velocity biomarkers

Conclusions

The proposed computational approach identified a waveform-based biomarker, minimum velocity gradient, which is more sensitive to the inception and progression of the pathology than current clinical diagnostic measures. The results and methodology of this study have the potential not only to improve the diagnosis and monitoring of vasospasm, but also to be used in the diagnosis of many other cardiovascular diseases where cardiovascular waves can be decoded to provide disease characterisation.

Acknowledgements

We gratefully acknowledge funding from the UK Engineering and Physical Sciences Research Council (Grant Number EP/K037145/1). This was partly supported from the European Union’s Horizon 2020 Research and Innovation programme under grant agreement No 675451, project CompBioMed.

[1] J Max Findlay, Joshua Nisar, and Tim Darsaut. Cerebral vasospasm: a review. *Canadian Journal of Neurological Sciences/Journal Canadien des Sciences Neurologiques*, pages 1–18, 2015.

[2] A. Melis, R. H. Clayton, and A. Marzo. Bayesian sensitivity analysis of a 1D vascular model with gaussian process emulators. *International Journal for Numerical Methods in Biomedical Engineering,* 2017. cnm.2882.

The University Of Sheffield.

Sheffield Teaching Hospitals NHS
NHS Foundation Trust

The Insigneo Institute for *in silico* Medicine is a collaborative initiative between the University of Sheffield and Sheffield Teaching Hospitals NHS Foundation Trust.