Use of a Gaussian process emulator and 1D circulation model to characterize cardiovascular pathologies and guide clinical treatment

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Abstract

Cerebral vasospasm (CVS) is a life-threatening condition that occurs in a large proportion of those affected by subarachnoid haemorrhage and stroke[1]. CVS manifests itself as the progressive narrowing of intracranial arteries. It is usually diagnosed using Doppler ultrasound, which quantifies blood velocity changes in the affected vessels, but has low sensitivity when CVS affects the peripheral vasculature. The aim of this study was to identify alternative biomarkers that could be used to diagnose CVS. We used a verified and validated 1D modelling approach[2] to describe the properties of pulse waves that propagate through the cardiovascular system (Figure 1), which allowed the effects of different types of vasospasm on waveforms to be characterised at several locations within a simulated cerebral network. A sensitivity analysis empowered by the use of a Gaussian process (GP) statistical emulator was then used to identify waveform features that may have strong correlations with vasospasm. A GP emulator can treat inputs and outputs explicitly as uncertain quantities, and so by determining the proportion of output variance that could be accounted for by each uncertain input we were able to calculate variance-based sensitivity indices for each input and output of the model. This was useful to identify those waveform features that are sensitive to vasospasm (changes in vessel radii) but less sensitive to physiological variations in the other model parameters. Using this approach, we showed that the minimum rate of velocity change can be much more effective than blood velocity for stratifying typical manifestations of vasospasm and its progression[3]. In the wider context, the present study describes the use of sensitivity indices, combined to modelling, as a way to identify effective biomarkers, which is a novel approach that has the potential to result in clinically useful tools.

The same approach has been further developed and applied to the simulation of endovascular removal of blood clots (thrombectomy) as a potential clinical tool to investigate typical clinical scenarios for treatment of ischaemic stroke.

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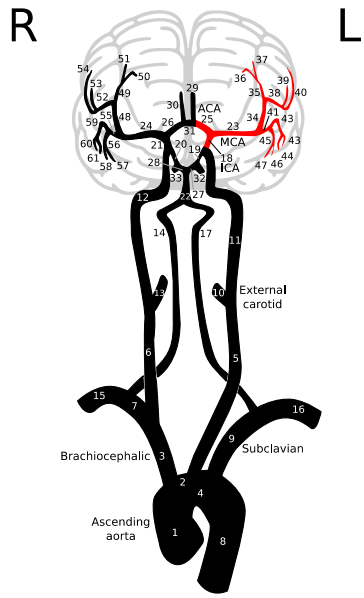

Figure 1 *Diagram of the complete cerebral vascular network model.*

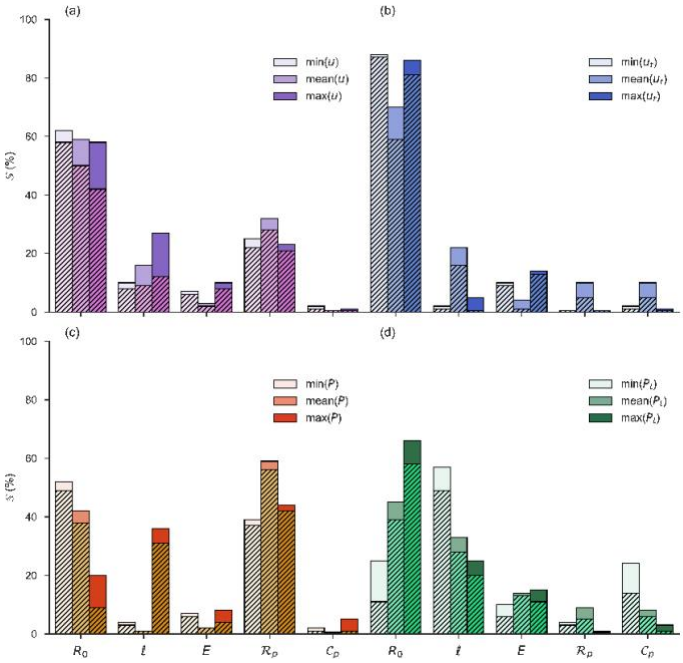

Figure 2 *Sensitivity indices for u (velocity) and P (pressure) biomarkers against variations of the model input parameters (R_0 lumen radius, ℓ vessel length, E Young's modulus, R_p peripheral resistance, and C_p peripheral compliance). Each plot shows sensitivity indices for each input. The hatched section of the bars shows the first-order sensitivity indices, and the plain sections the total-order indices. Thus, the height of the hatched bar shows the biomarker sensitivity to a single input and the plain section the sensitivity to multiple inputs.*

References

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