MODELLING MIDLINE SHIFT AND VENTRICLE COLLAPSE IN POST-STROKE CEREBRAL OEDEMA

Xi Chen[1], Tamás I. Józsa[1,2], Stephen J. Payne[1,3]

1. *Institute of Biomedical Engineering, Department of Engineering Science, University of Oxford, United Kingdom*
2. *Department of Radiology and Nuclear Medicine, Amsterdam University Medical Centre, Amsterdam, Netherlands*
3. *Institute of Applied Mechanics, National Taiwan University, Taiwan*

Introduction

Intracranial pressure (ICP) is a crucial parameter for the evaluation of and clinical decision-making in post-stroke oedema. In recent decades, the midline shift of edematous brain has been used to estimate ICP non-invasively since it can be observed directly on brain imaging. Although previous studies have shown a linear relationship between ICP and MLS, this relationship lacks statistical significance [1]. Therefore, MLS is not sufficient for the estimation of ICP. In this study, we thus propose the first poroelastic model to study the relationship between ICP and MLS and explore the factors that can cause deviations from a linear relation.

Methods

A new mathematical model of brain ischaemic stroke and oedema is proposed as a predictive tool to estimate the relation between ICP and MLS in different types of post-stroke oedema in varying degrees of brain damage. The model consists of two components that simulate blood perfusion and oedema respectively. The cortical surface was subdivided into 8 perfusion territories (Fig. 1) according to vessel encoded arterial spin labelling magnetic resonance imaging and the brain modelled as a multi-compartment porous medium [2]. In this study, a population-averaged brain model is used.

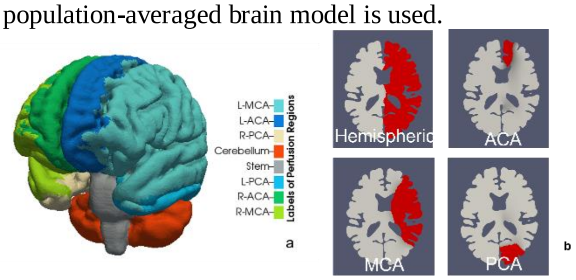

Figure 1: (a) Poroelastic brain model and sub-perfusion territories. (b) Simulation of brain damage in different types of ischaemic stroke.

Results

Different types of brain edema (resulting from ACA, MCA, PCA, hemispheric strokes) show significantly different MLS-ICP curves (Fig. 2). The permeability of the capillary network (which represents the severity of oedema) is also found to affect the relationship (Fig. 3). Note that only pathological parameters are varied while the physiologically-based parameters remain constant.

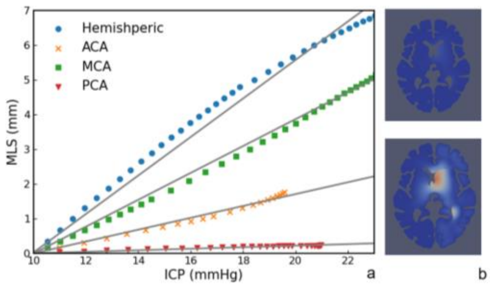

Figure 2: (a) ICP-MLS relationship in hemispheric, ACA, MCA and PCA stroke oedema. (b) 2D brain slices before and after deformation.

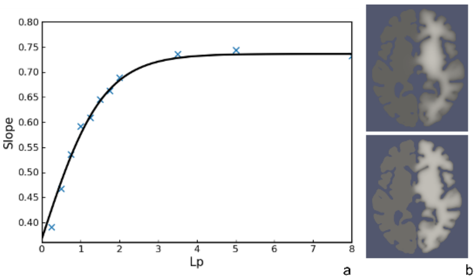

Figure 3: (a) ICP-MLS linear fit slope in hemispheric oedema, with varying severity of brain damage. (b) water content rise in more severe brain damage leads to large MLS.

Discussion

The simulation results show that the type of post-stroke edema has a significant impact on the ICP-MLS relationship, with the ACA and PCA stroke oedema induce deformation from both the top and bottom. In contrast, MCA stroke oedema swells and compresses the brain from the side and thus contributes the most to MLS. Meanwhile, variations in capillary permeability indicates that the MLS is not only affected by the maximum pressure rise, but also the distribution of excessive water in the brain tissue. This suggests that patient-specific modelling of the ICP-MLS relationship is necessary to improve the accuracy of ICP estimation.

References

1. Miller et al. (2004).. Journal of Trauma and Acute Care Surgery, 56(5), 967-973.
2. Józsa, T. I. et al. (2021). Interface Focus, 11(1), 20190127.