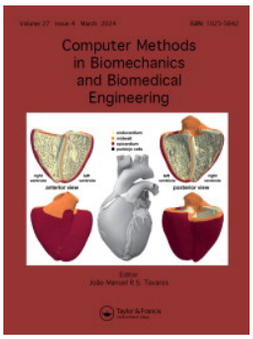

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Poroelastic modelling of brain tissue swelling and decompressive craniectomy treatment in ischaemic stroke

Aina Najwa Nadzri[a], Nik Abdullah Nik Mohamed[b], Stephen J. Payne[c] and Mohd Jamil Mohamed Mokhtarudin[a]

[a]Faculty of Manufacturing and Mechatronics Engineering Technology, Universiti Malaysia Pahang, Pekan, Pahang, Malaysia; [b]Faculty of Engineering, Technology and Built Environment, UCSI University Kuala Lumpur, Kuala Lumpur, Malaysia; [c]Institute of Applied Mechanics, National Taiwan University, Taipei, Taiwan

ABSTRACT

Brain oedema or tissue swelling that develops after ischaemic stroke can cause detrimental effects, including brain herniation and increased intracranial pressure (ICP). These effects can be reduced by performing a decompressive craniectomy (DC) operation, in which a portion of the skull is removed to allow swollen brain tissue to expand outside the skull. In this study, a poroelastic model is used to investigate the effect of brain ischaemic infarct size and location on the severity of brain tissue swelling. Furthermore, the model will also be used to evaluate the effectiveness of DC surgery as a treatment for brain tissue swelling after ischaemia. The poroelastic model consists of two equations: one describing the elasticity of the brain tissue and the other describing the changes in the interstitial tissue pressure. The model is applied on an idealized brain geometry, and it is found that infarcts with radius larger than approximately 14 mm and located near the lateral ventricle produce worse brain midline shift, measured through lateral ventricle compression. Furthermore, the model is also able to show the positive effect of DC treatment in reducing the brain midline shift by allowing part of the brain tissue to expand through the skull opening. However, the model does not show a decrease in the interstitial pressure during DC treatment. Further improvement and validation could enhance the capability of the proposed poroelastic model in predicting the occurrence of brain tissue swelling and DC treatment post ischaemia.

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KEYWORDS
Poroelastic model; brain tissue swelling; decompressive craniectomy; ischaemic stroke

1. Introduction

A stroke occurs when the continuous supply of blood carrying oxygen and nutrients to the brain tissue is interrupted (Coupland et al. 2017) hence resulting in brain cells not receiving enough oxygen to perform its healthy functions. Strokes can be divided into two types, namely ischaemic and haemorrhagic (Grysiewicz et al. 2008). About 85% of overall stroke occurrence worldwide is caused by ischaemic stroke, in which the blood flow interruption is caused by blockage of a blood vessel by a blood clot formation or a cholesterol deposit (Murphy and Werring 2020). The remaining stroke cases are haemorrhagic, which occur due to bleeding in the brain from blood vessel leakage (Murphy and Werring 2020). This simulation study will focus on ischaemic stroke as it is more common.

Prolonged ischaemic stroke can cause irreversible damage to the brain. Brain oedema usually develops a few hours after the onset of ischaemia and is the main cause of patient death (Muscari et al. 2019). There are two types of brain oedema, namely cytotoxic and vasogenic. Cytotoxic oedema occurs when the brain tissue metabolism starts to fail and not to function optimally. This leads to the disruption of the transmembrane ion balance, creating transmembrane osmotic gradients. The pressure gradient causes water to flow into the brain cells, resulting in cellular swelling (Kahle et al. 2009). On the other hand, vasogenic oedema occurs when ischaemia causes severe damage to the brain blood vessels. The brain blood vessel possesses a specialized layer known as the blood-brain barrier, which restricts the size of particles passing through it (Kahle et al. 2009). Prolonged ischaemia may damage the BBB and hence alter the permeability of the blood vessels. This causes solutes and water to exit the blood vessels and increases the brain tissue volume, especially close to the brain ischaemic lesion (Bebawy 2012).

CONTACT Mohd Jamil Mohamed Mokhtarudin mohdjamil@ump.edu.my