11º CONGRESSO NACIONAL DE BIOMECÂNICA
A. P. G. Castro, C. Pina, P. R. Fernandes, C. Santos, J. Folgado & A. Amaro (Eds)
Sesimbra, Portugal, 21-22 de Fevereiro, 2025

IN-SILICO MODEL OF DECOMPRESSIVE CRANIECTOMY

João Gonçalves, Renato Ferreira, Helena Ferreira, Matthis Krondorf and Rui Miranda Guedes

LAETA-INEGI, DeMec-FEUP, Universidade do Porto, Portugal

up201906648@up.pt; up201806462@up.pt: up201706264@up.pt; up202302722@up.pt; rmguedes@fe.up.pt

KEYWORDS: Decompressive craniectomy, In-silico modelling, Hyperelasticity

1 ABSTRACT

The aim is to provide an overview of decompressive craniectomies and to perform a prelaminar numerical simulation of this surgical procedure.

Surgical reduction of intracranial pressure by this technique does not necessarily lead to better patient outcomes and, at least in some circumstances, appears to worsen them. However, it is important not to simply abandon the procedure. Rather, the risks and benefits of decompressive craniectomy need to be considered more carefully before the procedure is performed, and appropriate clinical settings for the procedure need to be defined [1]. This work reviews the material characterisation of the brain and the mechanics behind craniectomy, which provide important information for in silico modelling of craniectomy.

2 INTRODUCTION

Decompressive craniectomy (DC) is a surgical treatment for diffuse cerebral edema or focal hematomas that cause intracranial hypertension (ICP). The benefit of DC is to reduce ICP and the risk of herniation, and to reduce secondary injury by improving brain tissue oxygenation, cerebral perfusion and cerebral metabolism. However, the use of DC as an early treatment may lead to poor outcomes, possibly due to persistent or increased intracranial hypertension (despite decompression) or to significant complications. Careful selection of patients for this potentially life-saving therapy is therefore essential [2].

3 BIOMECHANICS OF D.C.

The mechanical nature of decompressive craniectomies essentially describes the way the brain behaves when subjected to stress and strain perioperatively.

The main reason for performing decompressive craniectomies is an uncontrolled increase in intracranial pressure due to haemorrhage, infection, tumour growth, high altitude, ischaemic stroke or traumatic brain injury. The increase in pressure leads to tissue compression and damage to blood vessels. Intracranial pressure is considered worthy of intervention when it is 20 mmHg or higher [3].

The main dilemma faced by neurosurgeons when treating a patient with cerebral swelling is a mechanical problem of stresses and strains: on the one hand, high stresses due to increased intracranial pressure lead to ischaemia and therefore tissue death; on the other hand, surgical opening of the skull relieves the pressure, but critically high strains (as low as 3-5%) occur, which can cause permanent damage to axons (one of the main structures that make up neurons) [3]. This critical feature imposes a minimum size of the opening radius, a, to limit the height of the bulge to h=0.3a, suggesting that swelling volumes of 80-160 cm^3 requires a_{min} = 5-6 cm.

4 BIOMECHANICAL SIMULATIONS OF DC

A simplified model based on the bulging problem described above was created in Abaqus (Figure 1). The model is axisymmetric in nature and consists of a 100x100mm deformable shell (representing a portion of the brain) and an analytical rigid wire with a radius of 1.5mm (representing the skull-perforation boundary). The distance between the axis of symmetry and the cranial opening is 65 mm, based on the 12-15 cm diameter opening for surgical practice given in [3].

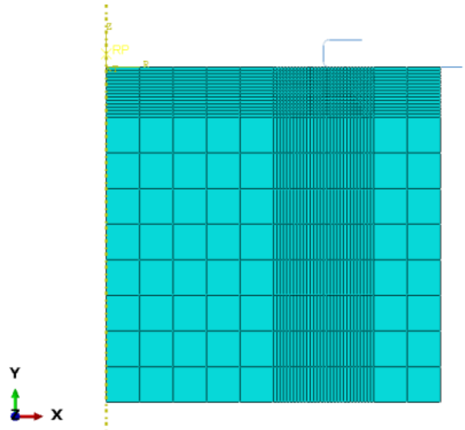

Figure 1 – Mesh model.

The maximum absolute vertical logarithmic strain occurs close to the wire radius, the maximum positive value of this variable occurs close to the axis of symmetry (Figure 2). The ranges of values differ from [4], but this may be since the strains presented in this report are logarithmic. Regarding the bulging itself, as expected, the maximum vertical displacement occurs for $r = 0$ (axis of symmetry) and reaches a value of 4.312 mm. The results depend strongly on the model used and on how the tissue properties were measured.

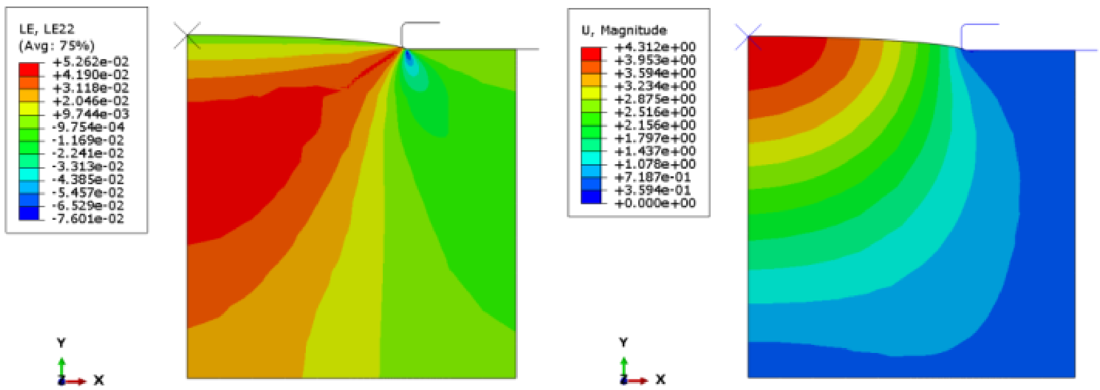

Figure 2 – Contour plot of vertical logarithmic strain (left) and displacement amount (right) in the current configurationl.

REFERÊNCIAS

[1] F. Servadei, “Clinical Value of Decompressive Craniectomy,” New England Journal of Medicine, vol. 16, no. 364, p. 1558–1559, 2011.

[2] R. M. CHESNUT, “Neurocritical Care Management of the Neurosurgical Patient E-Book, Decompressive Craniectomy for the Treatment of Traumatic Brain Injury, 2017, p. 293.

[3] J. Weickenmeier, E. Kuhl and A. Goriely, “The mechanics of decompressive craniectomy: Bulging in idealized geometries,” Journal of the Mechanics and Physics of Solids, no. 96, pp. 572-590, 2016.

[4] T. L. Fletcher, A. G. Kolias, P. J. Hutchinson and M. P. Sutcliffe, “A new improved method for assessing brain deformation after decompressive craniectomy,” PloS one, vol. 10, no. 9, p. e110408, 2014.