A non-linear poroelastic constitutive model for the computational modelling of brain tissue behaviour

Ester Comellas* and Paul Steinmann

Chair of Applied Mechanics (LTM), Friedrich-Alexander Universität Erlangen-Nürnberg,
Egerlandstr. 5, 91058 Erlangen, Germany
e-mail: ester.comellas@fau.de, web page: http://www.ltm.uni-erlangen.de/

ABSTRACT

The mechanical response of the brain is known to play a crucial role in modulating both its structure and function [1]. Deformations, pressure, and strain rate, among other mechanical factors, are known to influence brain development, injury and disease. Capturing the complex mechanical behaviour of brain tissue through computational analysis contributes to advance our understanding of this fascinating organ and can potentially provide tools to improve prognosis and treatment of brain pathologies in a clinical context.

Being a porous, fluid-saturated nonlinear solid, brain tissue can be modelled within the framework of the theory of porous media [2]. The material is treated as an immiscible aggregate of a solid skeleton constituent and a pore fluid constituent at each point P of the continua (see Figure 1). Then, the weak form of the problem in the reference configuration reads,

$$\int_{\mathcal{B}_0} \delta\mathbf{F} : \mathbf{P}\,\mathrm{d}V = P^{ext}(\delta\mathbf{u}) \quad \forall\delta\mathbf{u},$$

$$\int_{\mathcal{B}_0} \delta p\,\dot{J}\,\mathrm{d}V + \int_{\partial\mathcal{B}_0} \delta p\,\mathbf{W}\,\mathrm{d}S = \int_{\mathcal{B}_0} \mathrm{Grad}(\delta p)\cdot\mathbf{W}\,\mathrm{d}V \quad \forall\delta p,$$

where **u** are the displacements and *p* is the pore pressure. The term **W** includes a Darcy-like law to describe the flow of the fluid through the porous medium, whilst the Piola stress **P** captures the behaviour of the nearly-incompressible solid constituent, including the viscous and damage contributions.

The thermodynamic basis and formulation of the model is presented as well as the numerical algorithm implemented in the open source finite element library deal.II [3]. Numerical examples are used to verify and validate results with experimental data from literature.

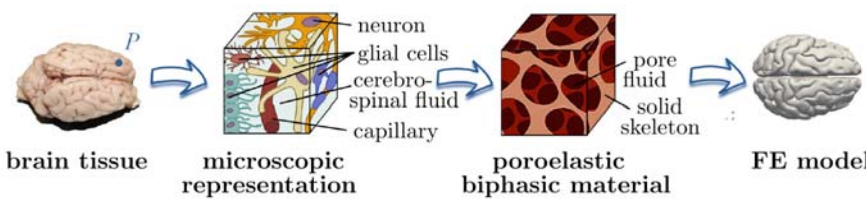

Figure 1 Poroelasticity (macroscopic continuum theory) is used to computationally model the constitutive behaviour of brain tissue, whose main components (at microscopic level) are brain cells and interstitial fluid.

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