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An Arbitrary Lagrangian-Eulerian Finite Element Formulation for a Poroelasticity Problem Stemming from Mixture Theory

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Abstract

A finite element formulation is developed for a poroelastic medium consisting of an incompressible hyperelastic skeleton saturated by an incompressible fluid. The governing equations stem from mixture theory and the application is motivated by the study of interstitial fluid flow in brain tissue. The formulation is based on the adoption of an arbitrary Lagrangian-Eulerian (ALE) perspective. We focus on a flow regime in which inertia forces are negligible. The stability and convergence of the formulation is discussed, and numerical results demonstrate agreement with the theory.

Keywords: Finite Element Method; Theory of Mixtures; Poroelasticity; ALE Formulation

1 Introduction

A central problem in brain physiology is the transport of metabolites produced by cell functions in brain tissue from their production site to the main cerebrospinal fluid (CSF) compartment (Iliff et al., 2013; Iliff and Nedergaard, 2013; Iliff et al., 2012, 2013). The modeling of these transport phenomena has traditionally focused on Fickian diffusion within the extracellular space (Syková, 2004; Syková and Nicholson, 2008; Vargova et al., 2011; Vargova and Syková, 2011) (see also Gevertz and Torquato, 2008). More recently, the studies by Iliff and co-workers (Iliff et al., 2013; Iliff and Nedergaard, 2013; Iliff et al., 2012, 2013) point to the existence of pathways for metabolite exchange with significant convective transport. Furthermore, evidence indicates that such convective component is driven by the pulsatile motion of arterial walls along the various elements of the brain vascular tree.

The coupling between transport and mechanical properties is a fundamental aspect of the design of tissue engineered scaffolds, especially for application in the regeneration of peripheral nerves (Dey et al., 2010, 2008; Nguyen et al., 2015; Saracino et al., 2013). In these applications, it is essential to coordinate the evolution of the transport and mechanical properties with the rate of degradation of the material. Modeling of these systems requires a framework for the system's poroelastic behavior along with the reaction-diffusion physics of the degradation process.

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