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Research paper

Experimental verification of brain tissue incompressibility using digital image correlation

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ABSTRACT

For decades, incompressibility has been a major assumption in the mechanical study of brain tissue. This assumption is based on the hydrated nature of the biological tissues and the incompressibility of fluids. In this paper, an experimental validation of this assumption using digital image correlation is presented. Unconfined compression tests, relaxation tests and cyclic tests were performed on cylindrical samples of swine brains at loading rates suitable for neurosurgical applications. Digital image correlation was used to evaluate the evolution of the volume ratio throughout the tests. The preparation of the samples is described and it is demonstrated that it causes no statistically significant change of their mechanical properties. The results indicate that the brain tissue incompressibility assumption is verified.

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1. Introduction

Brain modeling is an issue with several applications in various domains: study of hydrocephalus, neurosurgery planning and simulation, design of haptic devices, improvement of image-guided neurosurgery and optimization of security equipments are some examples amongst others. For years, efforts have been brought to adequately characterize brain tissue constitutive laws. For instance, Miga et al. (2000) have followed the poroelastic approach as well as Franceschini (2006) who applied the consolidation theory to brain tissue in her Ph.D. thesis. Miller and Chinzei (1997, 2002) and Miller (1999) used a hyperviscoelastic model based on a strain energy density suitable at strain rates encountered in surgical operations. Brands et al. (2004) and Darvish and Crandall (2001) concentrated their efforts on 3D non-linear viscoelastic constitutive equations for the study of brain tissue under impact loading while Velardi et al. (2006) claimed that viscous effects can be disregarded in such loading.

All these models assume brain tissue incompressibility, which seems to be a reasonable assumption regarding the hydrated nature of the tissue and the incompressibility of fluids. Nevertheless, as stated by Kyriacou et al. (2002), there is a lack of rigorous experimental data useful for demonstrating brain tissue incompressibility.

Incompressibility proved to be a major parameter in finite element analysis of brain shift: Wittek et al. (2009) demonstrated that the results were not very sensitive to the

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