Preface

SPECIAL ISSUE ON BRAIN NEURO-MECHANICS

In July 2010, the Centre for Mathematical Medicine organized the first interdisciplinary workshop on Brain Neuro-Mechanics, under the patronage of the Fields Institute. The focus of the workshop was on recent discoveries in fundamental brain science that could play an important role in improved medical diagnoses, treatment strategies and clinical protocols. The workshop brought together experts from different areas of brain research (applied mathematics, neuroscience, engineering, neurosurgery) who presented the latest developments in their fields and discussed new approaches that could link the brain’s biomechanical and biochemical processes occurring at different length and time scales, and thus could account for the interactions and feedback among the brain’s numerous networks. The aim of this special issue of the journal is to present the work of some of the invited speakers at this workshop.

The paper by Alan Wineman provides a basic review of the continuum mechanics framework and some important mathematical concepts that any researcher in this interdisciplinary field should be aware of, when developing biomechanical models of the brain. An MRI-based finite element approach to study traumatic brain injuries is proposed in the paper by Chen, Sutton, Conway, Broglio, and Ostoja-Starzewski. The authors use tagged MRI and the harmonic phase (HARP) imaging analysis technique developed originally for cardiac motion analysis, to study in vivo human brain deformation under mild impact, induced by a 2-cm head drop. This is the first study that correlates deformation fields obtained by MRI-based assessment with the predictions of a corresponding FE model, and also validates an FE brain injury model on in vivo human brain deformation data.

The following papers report on recent advances made in the understanding of the underlying mechanisms that give rise to hydrocephalus. Hydrocephalus, or water on the brain, is a brain condition known from the time of Hippocrates (ca. 460 BC - ca. 370 BC) and characterized by an abnormal accumulation of spinal fluid within the fluid-containing spaces of the brain. The paper by Wilkie, Drapaca, and Sivaloganathan summarizes recent work by the authors to study whether the cerebrospinal fluid (CSF) pulsations are capable of enlarging the cerebral ventricles by an amount similar to that observed in hydrocephalus. The results of the linear poroelastic and linear viscoelastic models indicate that CSF pulsations in a healthy brain cannot produce tissue damage and the ventricular enlargement observed in hydrocephalus. The final model presented in this paper is of hyper-viscoelastic type and suggests that small long-term transmantine pressure gradients may be a possible cause of communicating hydrocephalus in infants. The paper by Sobey, Eisentraeger, Benediktwirth, and Czosnyka presents a novel multi-fluid (blood and CSF) poro-elastic model of hydrocephalus which incorporates blood pulsations on the cardiac cycle time scale and thus can be used to simulate spinal fluid pressure fluctuations in clinical infusion tests. This model shows good agreement with clinical data where the infusion rate and arterial blood pressure are input and an oscillatory CSF pressure is computed along with spatial parenchyma displacement, strain and local changes in CSF content. The authors also provide a careful analysis of parameter value calculations when the arterial pressure pulsations are included in the proposed model. Recent experiments by Miles Johnston and co-workers shows
that, in the rat brain, interstitial fluid pressures increase after antibody administration into a lateral ventricle - this suggests that capillary absorption might play a pivotal role in the onset of hydrocephalus. Based on these findings, Wilkie, Nagra and Miles Johnston present two poroelastic models to investigate the role of intramantle pressure gradients in ventriculomegaly and suggest that integrin-matrix disassociation could be a complete causative mechanism for the development of at least some forms of hydrocephalus. The paper by Drapaca and Fritz proposes the first neuro-mechanical model that couples brain biomechanics and biochemistry to study the onset of normal pressure hydrocephalus (NPH), a form of hydrocephalus more commonly seen in the older population. The model, based on triphasic theory, assumes that the brain is a charged hydrated soft tissue made of a solid phase, an interstitial fluid phase and an ionic phase which (for now) is assumed to be comprised of two monovalent ionic species. Using this model, the authors show that NPH can arise as a result of an increase in the concentrations of sodium and chloride in the ventricular CSF, even in the absence of an elevated intracranial pressure. This appears to be in agreement with the results from the NuAge study by Fiocco et al (Neurobiology of Aging, first published online August 22, 2011) that show that older individuals (above 67 years of age) who lead sedentary lifestyles and consume a lot of sodium in their diet may be at risk for cognitive decline. The findings presented in these last two papers point to the exciting possibility that some forms of hydrocephalus may be treatable with pharmacological agents rather than through surgical interventions. Finally the paper by Palocaren and Drapaca propose a non-invasive way of classifying gliomas, p based on their stiffness. Their model uses image mass spectra of proteins present in gliomas and shows that the Young's modulus of a high grade glioma is at least 10kPa higher than the Young's modulus of a low grade glioma. The authors use this model to investigate the effect of mechanics on the growth of gliomas. The proposed mechano-growth model is a non-linear evolution differential equation which is solved analytically using the Adomian method. Their results show that the fractional order model captures a very interesting temporal multi-scale effect of tumor transition from a low grade (benign) to a high grade (malignant) glioma when a certain threshold of mechanical strain is exceeded in the tissue.

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