Journal of Biomechanics 44 (2011) 1909–1913

Contents lists available at ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

Viscoelastic properties of human cerebellum using magnetic resonance elastography

John Zhang [a,b], Michael A. Green [a], Ralph Sinkus [c], Lynne E. Bilston [a,d,*]

[a] Neuroscience Research Australia, Barker Street, Randwick NSW 2031, Australia
[b] Faculty of Medicine University of New South Wales, Kensington, NSW 2052, Australia
[c] INSERM U773, CRB3, Centre de Recherches Biomédicales Bichat-Beaujon, Paris, France
[d] Prince of Wales Clinical School, University of New South Wales, Kensington NSW 2052, Australia

ARTICLE INFO

Article history:
Accepted 19 April 2011

Keywords:
Brain viscoelasticity
Shear modulus
Magnetic resonance imaging
In vivo measurements

ABSTRACT

Background: The cerebellum has never been mechanically characterised, despite its physiological importance in the control of motion and the clinical prevalence of cerebellar pathologies. The aim of this study was to measure the linear viscoelastic properties of the cerebellum in human volunteers using Magnetic Resonance Elastography (MRE).

Methods: Coronal plane brain 3D MRE data was performed on eight healthy adult volunteers, at 80 Hz, to compare the properties of cerebral and cerebellar tissues. The linear viscoelastic storage (G') and loss moduli (G'') were estimated from the MRE wave images by solving the wave equation for propagation through an isotropic linear viscoelastic solid. Contributions of the compressional wave were removed via application of the curl-operator.

Results: The storage modulus for the cerebellum was found to be significantly lower than that for the cerebrum, for both white and grey matter. Cerebrum: white matter (mean $\pm$ SD) $G'=2.41\pm0.23$ kPa, grey matter $G'=2.34\pm0.22$ kPa; cerebellum: white matter, $G'=1.85\pm0.18$ kPa, grey matter $G'=1.77\pm0.24$ kPa; cerebrum vs cerebellum, $p<0.001$. For the viscous behaviour, there were differences in between regions and also by tissue type, with the white matter being more viscous than grey matter and the cerebrum more viscous than the cerebellum. Cerebrum: white matter $G''=1.21\pm0.21$ kPa, grey matter $G''=1.11\pm0.03$ kPa; cerebellum: white matter $G''=1.1\pm0.23$ kPa, grey matter $G''=0.94\pm0.17$ kPa.

Discussion: These data represent the first available data on the viscoelastic properties of cerebellum, which suggest that the cerebellum is less physically stiff than the cerebrum, possibly leading to a different response to mechanical loading. These data will be useful for modelling of the cerebellum for a range of purposes.

1. Introduction

The viscoelastic properties of brain tissue play a role in a variety of neurological disorders and traumatic brain injury. It has been postulated that certain conditions, such as normal pressure hydrocephalus, are influenced by a change in the mechanical properties of the brain tissue (Pang and Altschuler, 1994; Dutta-Roy et al., 2008), and those changes in the viscoelasticity of the brain may be a marker for neurodegenerative conditions such as Alzheimer's disease and multiple sclerosis (Kruse et al., 2008; Wuerfel et al., 2010). In addition, these parameters are vital for computational simulations such as Finite Element Analysis (FEA) of brain conditions, traumatic brain injury, and surgical planning. To date, there have been a great number of rheological studies of the viscoelastic properties of the brain, generating data that vary by a considerable margin, reflecting the heterogeneity in methods employed by different research groups. Researchers have performed ex-vivo studies of cadaveric and animal brain tissues (e.g. (Bilston et al., 1997; Donnelly and Medige, 1997; Bilston et al., 2001; Miller and Chinzei, 2002; Hrapko et al., 2006)), measured the poroelastic properties (e.g. (Franceschini et al., 2006; Cheng and Bilston, 2007)), and developed many different types of constitutive models (e.g. (Bilston et al., 2001; Darvish and Crandall, 2001; Brands et al., 2004; Hrapko et al., 2006)). Brain tissue mechanical properties have been recently reviewed in detail elsewhere (Cheng et al., 2008). While the earliest studies only measured elastic properties of the brain (e.g. elastic shear modulus; McCracken et al., 2005), in recent years, the advent of Magnetic Resonance Elastography (MRE) has made possible the non-invasive measurement of brain viscoelasticity in living human

* Corresponding author at: Neuroscience Research Australia, Barker St, Randwick, NSW 2031, Australia.
E-mail address: L.Bilston@neura.edu.au (L.E. Bilston).

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doi:10.1016/j.jbiomech.2011.04.034