Research paper

Age-dependence of intracranial viscoelastic properties in living rats

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\textbf{A B S T R A C T}

To explore the effect of maturation on intracranial mechanical properties, viscoelastic parameters were determined in 44 live rats at ages 1–2, 10–12, 21, 56–70, and 180 days using instrumented indentation. With the dura mater intact, the apparent modulus of elasticity, the indentation modulus, and viscous behavior were measured in vivo, as well as 1 h after death. In a separate group of 25 rats, brain water, and protein content were determined. A significant increase of the elastic and indentation moduli beginning at 10–12 days after birth and continuing to 180 days was observed. The creep behavior decreased in the postnatal period and stabilized at 21 days. Changes in intracranial biomechanical properties corresponded to a gradual decrease of brain water, and an increase in total protein content, including glial fibrillary acidic protein, myelin basic protein, and neurofilament light chain. Elastic properties were not significantly different comparing the live and dead states. However, there were significant postmortem changes in viscous behavior. Viscoelastic properties of living rat intracranial contents are shown to be age dependent, reflecting the physical and biochemical changes during postnatal development. This may be important for understanding why young and mature brains respond differently in situations of brain trauma and hydrocephalus.

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\section{1. Introduction}

The study of live brain mechanical properties in animal models offers the potential for understanding some aspects of the pathogenesis of human brain disease and brain injury. The properties of biological tissues including the brain, which have a non-uniform (i.e. anisotropic) microstructure, are viscoelastic; their strain response is dependent on the rate of stress (Fung, 1993; Spivack, 2001; Franceschini et al., 2006). Parenchymal fluids, especially extracellular water, are in equilibrium with blood and cerebrospinal fluid (CSF) circulations. Thus the mechanical properties of the brain are dependent on properties of individual cells, the organization of the cells, and the mobility of fluids within and between cells (Humphrey, 2003). Living intracranial viscoelastic behavior patterns are needed to predict brain mechanical response to and recovery from traumatic forces in computational modeling of brain injury, brain disease,