The impact of aging and gender on cerebral viscoelasticity


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Background: Physiological aging of the brain is accompanied by ubiquitous degeneration of neurons and oligodendrocytes [1]. An alteration of the cellular matrix of an organ impacts its macroscopic viscoelastic properties, which are characterized by mechanical parameters such as stiffness and internal friction.

Problem: To date almost nothing is known about alterations of in vivo cerebral viscoelasticity associated with diffuse structural changes during normal aging. Although conventional MRI has become the most important imaging modality, its capability to identify diffuse structural changes of the brain parenchyma is limited [2].

Objective: Combining MRI with acoustic waves is a promising way to measure cerebral viscoelasticity without intervention [3]. Recently, the technical feasibility of brain MR elastography was demonstrated [4-6]; A clinically applicable assay of multifrequency MRE of the brain was developed and applied to measure cerebral viscoelasticity as a function of age and sex in 55 individuals. Our hypothesis was that the viscoelasticity of the brain is sensitive to a widespread structural alteration occurring in the course of physiological aging. The results presented in this study are intended as background data for the future use of cerebral viscoelasticity as a marker of tissue integrity and diffuse degenerative processes.

Materials and Methods

55 volunteers without overt neurological or psychiatric conditions were recruited for this study (mean age 49.35 years, SD 18.78 years, age range 18 to 88 years; 31 males, mean age 52.74 years, SD 17.61 years, age range 21 to 84 years; 24 females, mean age 44.96 years, SD 19.70 years, age range 18 to 88 years). Experiments were run on a standard 1.5T clinical MRI scanner (Siemens, Erlangen, Germany). A custom-made head cradle was used for multifrequency head stimulation. Three transverse images slices with through-plane motion-encoding direction were chosen in a central slab through the cerebrum. 40 time-resolved phase-difference wave images, \( u(x,y,t) \) were Fourier-transformed for decomposition into complex wave images at driving frequency: \( U(x,y,\omega, (\omega / 2\pi = 25, 37.5, 50 \text{ and } 62.5 \text{ Hz}) \). Complex modulus images were obtained by wave inversion \( G(x,y,\omega, -\rho \omega^2 \mu U(x,y,t)) \) and spatially averaged. The resulting global modulus function was fitted by the springpot model \( G(x,y,\omega, \mu, \kappa) \) with \( \kappa \) and \( \epsilon \) as variables.

Results

We observed a strong decline in brain viscoelasticity with age. Fig.1 presents two sets of wave data obtained in a young and an elderly healthy female volunteer. Stiffness differences due to senescence are immediately perceptible by comparison of the wavelengths: since large shear wavelengths correspond to a high shear modulus (stiff material), the aged brain is clearly softer than the younger one. Clear sex differences were observed with female brains being in the order of 9% stiffer than those of males (\( P < 0.05 \)). This difference can be translated into a scale of viscoelastic age, according to which female brains were on average 13 years (\( P < 0.05 \)) younger than male brains (Fig.2). Viscoelastic values are summarized in tables 1 and 2.

Discussion

Elderly men and young women represented the minimum and the maximum in our range of brain viscoelasticities, respectively. Interestingly, this finding is not correlated to the volume of the adult brain, measured as brain parenchymal fraction, which is smallest in elderly females. We therefore conclude that brain geometry and volume only have a minor influence on our data. The parameter \( \alpha \) corresponds to the ratio of elastic and viscous properties and characterizes the structure of the tissue (corresponding to the hypothetical alignment of springs and dashpots). In contrast, the order of magnitude of viscoelastic parameters determines the solid-fluid behavior of the material given in \( \mu \) combining elastic and viscous information in the material property of viscoelasticity. Alteration in \( \mu \) indicates a continuous phase transition on a solid-fluid scale. This tissue “liquefaction” raises the question of how neurons and glial cells may contribute to the global mechanical properties of the brain parenchyma.

Conclusion

It was demonstrated that multifrequency MRE provides a sensitive measure of the global integrity of brain tissue. Using this new technique for the diagnosis of diffuse pathological processes, one needs to account for age- and gender related effects on viscoelastic constancy of the brain.
