Auto-elastography of the brain

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Introduction: In conventional MR elastography, a vibrating mechanical device is used to induce an audio frequency wave motion in tissue. Synchronised with the vibration, an imaging experiment is conducted to investigate the propagation of the wave in the tissue so that its shear modulus can be deduced. We report here a method of estimating the brain tissue's elasticity without use of an external mechanical device. We measure the brain's motion under the influence of CSF and blood pulsation using a phase contrast imaging technique and observe a damped oscillation in the brain tissue. We exploit this motion to measure the elasticity of the brain.

Data Acquisition: 5 healthy volunteers were scanned on a Philips 3T Achieva scanner. An FFE phase contrast quantitative flow imaging sequence with cardiac ECG gating was used with the following parameters: TR/TE = 30/14 ms; single 4 mm thick coronal slice through the brainstem; FOV of 150x150 mm; acquisition matrix 128x128 interpolated to 256x256; motion encoding along the foot-head direction with a sensitivity of 1 cm/s. The sequence uses a phase interval of 30 ms, and usually 23 to 28 cardiac phases are acquired depending on the heart rate of the volunteer. Total acquisition time is less than 5 minutes. Under the influence of gradient switching, the scanner bed also vibrates in synchrony with the cardiac gating, leading to a potential additional source of pulsation. We adjusted the timing of the first phase increment to sample the largest amplitude motion observed within the cardiac cycle.

Results: A damped oscillation pattern of motion is observed in the brain tissue against the gated cardiac phase time, as shown in Fig.1 and Fig.2.

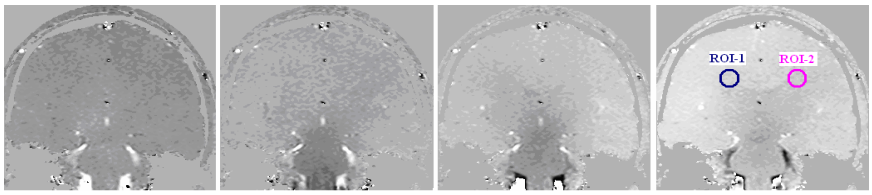

Fig.1. A subset of the phase contrast images shown at intervals of 90, 120, 150 and 180 ms. It can be seen that the motion in brain has gone from negative (dark) to positive (light) in these phases, with greatest motion observed in the brain stem and basal ganglia.

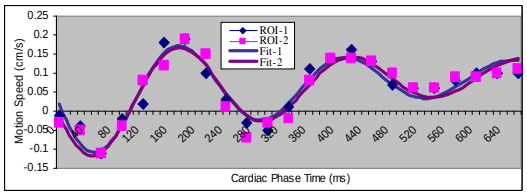

Fig.2. Plot of the tissue velocity from the two ROIs in Fig. 1, showing damped oscillation in the brain tissue plus damped oscillator model fits.

Data Analysis: We fit the damped oscillation with a 6 parameter model: $S(t,\mathbf{r}) = A(\mathbf{r}) + B(\mathbf{r})\,t + C(\mathbf{r})\exp(-\lambda(\mathbf{r})\,t)\cos(2\pi\, f(\mathbf{r})\,t + \Phi(\mathbf{r}))$, where A is a constant component of the signal, B is the slope of the linear term, C is the amplitude of the damped oscillation term, which has an exponential decay constant of λ, a frequency f and a phase angle Φ, and **r** is position in the brain.

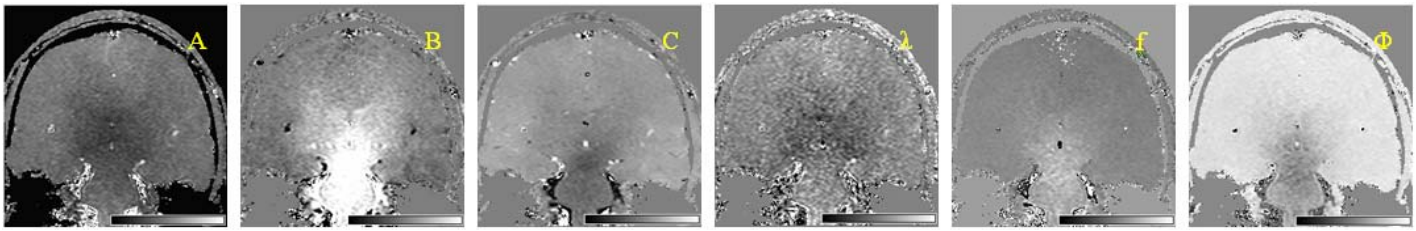

Fig.3. From left to right: fitted images of the parameters A, B, C, λ, f and Φ for the damped oscillation The displays are scaled as A: -0.25 to 0.25 cm/s, B:-0.25 to 0.25 cm/s^2, C: 0 to 0.5 cm/s, λ: 0 to 4 (ms)$^{-1}$, f:0 to 8 Hz, Φ: -5 to 5 rad respectively.

We estimate the shear modulus G by calculating the speed of wave propagation through the brain from the differential of the wave phase with respect to position $d\Phi/d\mathbf{r}$ (Fig 4). It is not easy to measure the wave speed at each pixel position, due to the small phase change and signal noise. We therefore apply Gaussian smoothing to the Φ map prior to a single wave speed calculation for the entire brain. We take a distance of Δy along the foot-head direction, measure the phase difference $\Delta\Phi$, then estimate the speed of wave as $c = 2\pi f \Delta y / \Delta\Phi$, where f is taken as the average value along Δy, and finally the shear modulus of the brain tissue as a whole can be obtained as in [1]: $G = \rho c^2$. For the 5 volunteers we obtain a value of 4.7 +/- 3.6 k N/m^2, which is within the range from literature [1].

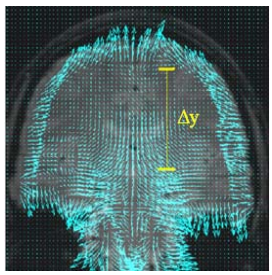

Fig.4. Vector plot of the gradient of fitted parameter phase map Φ overlaid onto the structural image of the coronal slice. The gradient is taken after the Φ map is smoothed using a Gaussian filter of a standard deviation 1.0 voxel.

Discussion: The brain motion that we observe is the net response of the tissue to pulsations provided by the blood and by scanner vibrations during the cardiac cycle. Separate phantom experiments (data not shown) show that bed vibration on its own is enough to allow measurement of wave propagation. However, the effect of blood and CSF pulsation dominates the measurements performed in the brain.

Our model of damped oscillations is a simple approach to describing the motion of the tissue due to the impulse of the blood entering the brain. However, this model appears to describe the data adequately and also provides the possibility for direct estimation of elasticity from the measured values of λ and f, which is the focus of current work.

Conclusion: We have demonstrated a novel method of deducing brain tissue's elasticity by utilising its motion due to blood, CSF and scanner table pulsation. This provides the possibility of measuring brain elasticity without the need for external mechanical drivers. This has potential important applications in a wide range of brain disorders including neurodegenerative, ischaemic and neoplastic diseases.

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Reference: 1. Kruse SA et al, Magnetic resonance elastography of the brain, NeuroImage, 39(2008) 231-237