Whole brain MRE with guided pressure waves

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Introduction

For a given acquisition sequence, the sensitivity of MR-elastography (MRE) relies on the strength of the shear waves, which may be induced in the targeted organ. For the brain, the head may be periodically tilted in a head-rocker system[1] or the subject may bite a vibrating bar to yield propagating waves[2,3]. However, for the last ten years, this remote organ has proven to be rather well decoupled from any mechanical excitations by the natural shielding layers provided by the surrounding meninges and skull. Waves generated through the bones are quickly attenuated inward and their amplitudes fall below the limit that is required to properly infer the viscoelastic properties of the tissue in the centre of the brain. A very different approach was taken here. By guiding pressure waves into the buccal cavity, it was possible to generate, throughout the brain, shear waves in the three spatial directions such that whole brain MRE could be performed and corresponding 3D maps of dynamic and loss shear moduli could be reconstructed.

Materials and methods

Pressure waves were generated at 50 Hz by a 40 W loudspeaker SPH-135/AD (Monacor, Germany) from the end of the scanner bed. They were guided to the subject's mouth *via* a silicon mouthpiece by a 20 mm diameter and 1760 mm long altuglass® tube connected to a pressure concentrator. The subject was supine and breathing normally through the nose. MRE measurements were obtained on a 1.5 T scanner (Achieva, Philips Medical Systems, The Netherlands) using a basic spin-echo sequence with 21 mT/m motion sensitizing gradients, synchronized with the mechanical wave. The whole brain was probed with $3{\times}3{\times}3$ mm^3 voxel size. FOV=$256{\times}149{\times}129$ mm^3, matrix=$84{\times}50{\times}43$, TE/TR=70/100 ms. Eight snap-shots of the wave propagation were acquired during the oscillatory cycle along the three directions right-left (phase), feet-head (measurement), and anterior-posterior (slice). Shear wavelength (λ), dynamic and loss shear moduli distribution maps (elasticity, G_d and viscosity, G_l) were computed from the acquired displacement fields following a 3D inversion method[4]. A reference anatomical data set was acquired using an inversion-recovery spin-echo sequence with TE=15 ms and TR/TI=3087/400 ms.
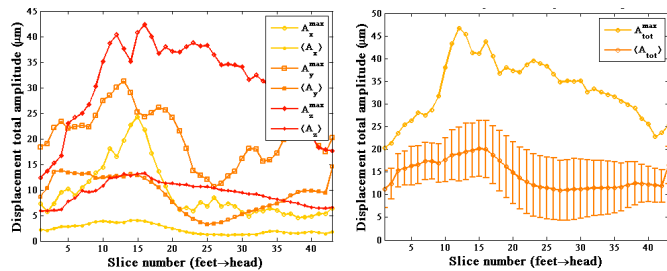

Figure 1: Mean and maximal displacement amplitudes for each slice along the three spatial directions (left) and the resulting total maximal and mean displacement amplitudes (right) throughout the 43 brain slices. Error bars represent the standard deviation of the distribution of the total amplitude for each slice.

Results and discussion

The signal to noise ratio was 70 in average over the whole brain, which ensured a mean error in the displacement field measurement lower than half a micrometer. Mean amplitudes per slice ranged between 1 and 4 µm along the right-left direction, 3 and 14 µm along the anterior-posterior direction, 6 and 13 µm along the feet-head direction. Displacements reached 24, 31, and 42 µm. The wave propagation is clearly eased and constrained by the orientation of the tissue fibers. Hence, the main entrance to the brain tissue is given by the brain stem along the feet-head direction from the medulla oblongata to the pons (see A_z^{max} between slices 1 to 13 on Figure 1). Above, waves along the feet-head direction propagate in the frontal and occipital lobes close to the front and the back of the head. In the cerebellum, tissues essentially oscillate along the right-left direction (see A_x^{max} between slices 1 to 15 on Figure 1). They never cross the falx cerebelli and barely propagate above the tentorium cerebelli (A_x^{max} falls down to 5 µm after slice 20 on

Figure 2: (a) Reference anatomical scan. (b) Wave amplitude A_{tot}, (c) shear wavelength λ, shear dynamic and loss moduli (d and e) superimposed onto the corresponding amplitude image for 6 of the 43 slices acquired to cover the brain.

Figure 1). The latter amplifies them when they are orthogonal, namely along the right-left direction, but the tentorium cerebelli represents a clear antinode for the other in-plane directions (see the low amplitude u-shape around the midbrain on slice 17 in Figure 2.b). Waves along the anterior-posterior direction are rather evenly supported by the temporal lobes and the upper parts of the parietal and frontal lobes (see the nodes at the lower tips of the temporal lobes on slice 10 and the large amplitude *quote*-shapes on both hemisphere on slices 17 to 38 in Figure 2.b). The wavelength λ takes its higher values mostly where white matter is expected and where the dynamic shear modulus G_d approaches 3 kPa. Both G_d and G_l maps nicely delineate most of the main brain structures and relevantly discriminate in a first approach white and grey matters (Figure 2 d, e, and a). In a second approach, they also point out nuclei that could not be distinguished on the anatomical scan.

The pressure wave build-up in the mouth provides an efficient mechanical wave generation and propagation throughout the brain structures. The achieved wave amplitude is not technically limited – the incident pressure can easily be increased – but the amplitude pattern and the penetration paths are physically determined by the brain structured tissues, which do not necessarily allow 3D wave propagation. The pressure wave setup is light and it favors patient comfort. The resulting wave amplitude ensures the sensitivity of the technique and leads here to a first atlas of the elasticity and viscosity of the human brain.

References

1. Sack *et al.* NMR Biomed **21**(3):265-71 (2008) **2.** Green *et al.* NMR Biomed. **21**:755-764 (2008) **3.** Kruse *et al.* NeuroImage **39**:231–237 (2008) **4.** *Si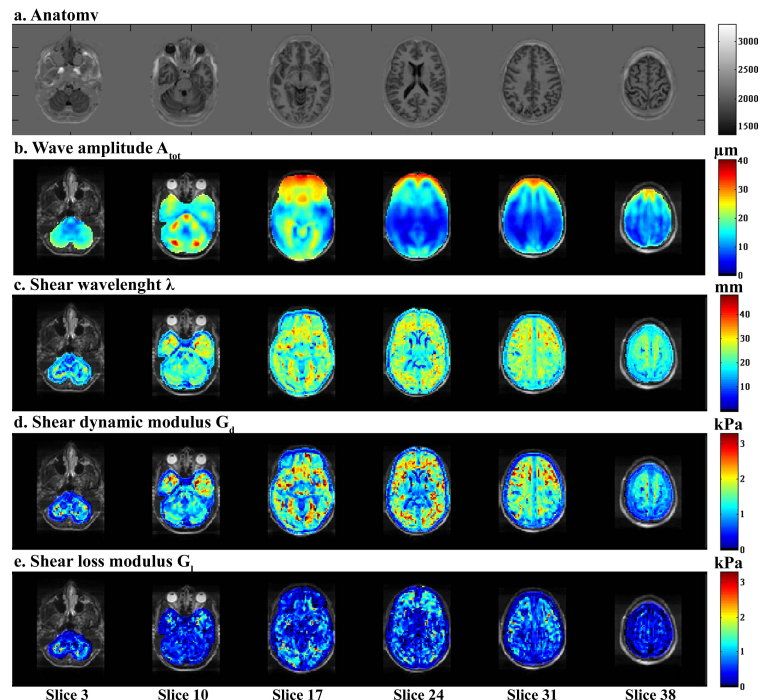nkus et al.* Magn Reson Med **58**:1135-1144 (2007)