

Brain MR Elastography using Optimized Mechanical Vibration of the Patient Table

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INTRODUCTION

Magnetic resonance elastography (MRE) is a noninvasive technique for measuring tissue elasticity [1]. In order to generate waves within the tissue, various external drivers have been proposed [2]. Alternatively, Gallichan et al. [3] suggested that the vibrations of the patient table that result from the impulse of an imaging gradient lobe could be used as a mechanical driving mechanism for MRE. The advantage of this approach is that it can be easily adapted for clinical application. However, the vibration frequency must be optimized so that high spatial resolution and accurate storage-modulus maps (elastogram) can be obtained. In this study, we add sinusoidally switching gradients before a conventional MRE pulse sequence and measure the amplitude of the patient table as it vibrates during acquisition. To evaluate the elasticity of the brain using the specific mechanical resonance frequencies of the patient table, heterogeneous phantom and *in-vivo* brain experiments are performed.

MATERIALS AND METHODS

A spin-echo EPI MRE sequence (SE-EPI-MRE) with vibration inducing gradient (VIG) was used for MRE data acquisition (Figure 1). Experiments were performed using a GE Signa HDx 3.0T with an eight-channel phased-array head coil. We directly measured the movement of the head coil on the MRI patient table during SE-EPI-MRE with VIG (MREwVIG) scanning using a laser Doppler vibrometer (Keyence Co.,Ltd, SI-F10). The MREwVIG experiments were conducted on a tissue-simulating heterogeneous polyacrylamide (PAAm) gel phantom and a healthy 23-year-old male subject. The gel phantom was 160 mm long and constructed with five cylindrical inclusions (diameter 10, 15, 20, 30, and 40 mm, gel storage-modulus 6.8 kPa) inside a larger cylinder (diameter 180 mm, gel storage-modulus 3.1 kPa). The imaging protocol for MREwVIG was: single-shot EPI, repetition time (TR) = 2000 ms, echo time (TE) = 65.2 ms (MSG=40 Hz), 50.3 ms (MSG=57 Hz), field of view (FOV) = 192 x 192 mm², image matrix = 64 x 64, slice thickness = 3 mm, number of slices = 9, number of excitations = 1, MSG cycles = 1, phase offsets = 8, maximum MSG gradient = 0.3 (*in-vivo* 4.0) mT/m, VIG and MSG frequency = 40, 57 Hz and VIG duration time = 1 s. VIG and MSG were applied on the x-axis. In order to calculate the elastogram, the local frequency estimation (LFE) method [4] was applied.

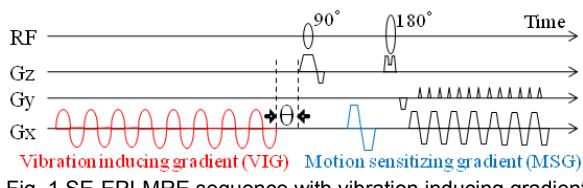


Fig. 1 SE-EPI-MRE sequence with vibration inducing gradient

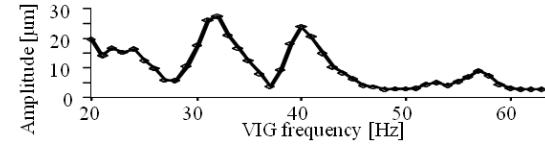


Fig. 2 Vibration amplitude of the patient table

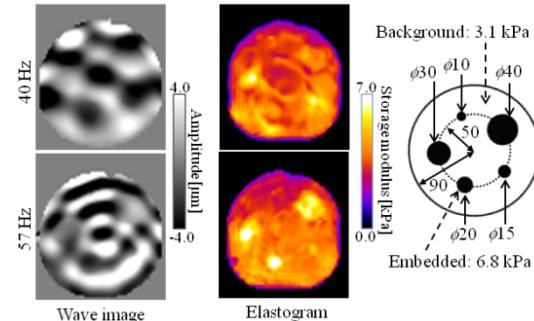


Fig. 3 Wave images and elastograms of the heterogeneous gel phantom (φ: diameter)

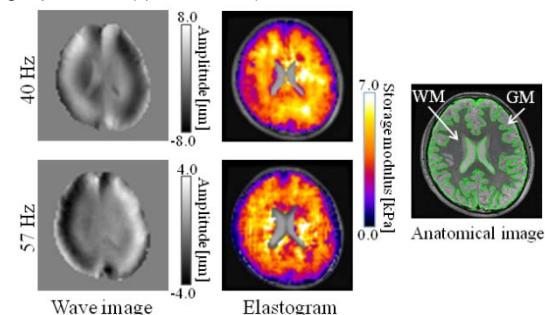


Fig. 4 Wave images and Elastograms of *in-vivo* human brain

RESULTS

Figure 2 shows the vibration amplitude of the patient table during MREwVIG scanning at each VIG frequency. The peaks at 32, 40, and 57 Hz have amplitudes of 27, 23, and 9 μm, respectively. Figure 3 shows shear wave images and elastograms for the heterogeneous PAAm gel phantom. The estimated shear moduli are shown in Table 1. The shear modulus of the embedded and background gels were measured by dynamic mechanical analysis at 10 Hz to be 6.8 kPa and 3.1 kPa, respectively. Figure 4 presents shear wave images and elastograms for *in-vivo* human brain. The estimated shear moduli are shown in Table 2.

DISCUSSION

The phantom studies show that the mechanical vibration of the patient table creates a shear wave of sufficient amplitude, but insufficient spatial resolution and accuracy at 40 Hz. The *in-vivo* studies at 40 Hz suggest that shear waves of sufficient amplitude to penetrate the whole brain could be generated and provide good contrast between gray and white matter. However, measurements at 57 Hz were less reliable in the deeper tissue.

CONCLUSION

In this study, we measured the vibration amplitude of the patient table during MREwVIG scanning as a function of VIG frequency. The results suggest that MREwVIG will enable quantitative measurement of the brain elasticity.

REFERENCES

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Table 1 Average storage-modulus of the heterogeneous phantom in each cylinder (Unit: kPa, φ: diameter, n/m: not measured)

| | φ10 | φ15 | φ20 | φ30 | φ40 | background |
|-------|-----|-----------|-----------|-----------|-----------|------------|
| 40 Hz | n/m | 5.8 ± 0.4 | 3.5 ± 0.5 | 5.3 ± 1.0 | 4.1 ± 0.4 | 3.5 ± 0.5 |
| 57 Hz | n/m | 5.0 ± 0.3 | 3.9 ± 0.3 | 5.7 ± 1.0 | 5.6 ± 0.6 | 3.9 ± 0.3 |

Table 2 Average storage-modulus of *in-vivo* human brain in gray matter (GM) and white matter (WM) regions (Unit: kPa)

| | GM | WM |
|-------|-----------|-----------|
| 40 Hz | 1.2 ± 0.7 | 1.7 ± 0.7 |
| 57 Hz | 1.7 ± 0.8 | 1.8 ± 1.2 |