Magnetic Resonance Elastography of the Human Brain: A Preliminary Study

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Purpose: To study the application of magnetic resonance elastography (MRE) in the human brain.
Material and Methods: An external force actuator was developed, which produced propagating shear waves in brain tissue. A modified phase-contrast gradient-echo sequence was developed. The propagating shear waves within the brain were directly imaged. The wave images were processed to obtain the elasticity image. Shear waves at 100 Hz, 150 Hz, and 200 Hz were applied.
Results: The propagating shear waves in the brain were visualized on wave images. The elasticity image revealed the difference in tissue elasticity between gray and white matter of the brain.
Conclusion: MRE could be an imaging technique for assessing the elasticity of brain tissue.

Key words: Brain; CNS; imaging sequences; MR imaging; tissue characterization

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Elasticity is an important physical property of human tissues. Palpation is a basic and effective clinical examination tool that has been used for centuries. In engineering terms, palpation assesses the tendency of tissue to resist deformation, a physical property called elastic modulus. However, brain tissue is not accessible to the palpating hand. Magnetic resonance elastography (MRE), proposed by MUTHUPILLAI et al. (7), is a noninvasive imaging technique that can directly visualize and quantitatively measure tissue elasticity. Most of the studies on MRE have been implemented with phantoms. To date, some researchers have conducted preliminary studies in human organs in vivo, including breast and prostate (1, 6). Because imaging of the brain is more complex, brain MRE studies are extremely rare in the literature.

MRE is a unique, noninvasive approach to evaluate the elasticity of brain tissue in vivo. MRE provides a novel examination tool for intracranial abnormalities by assessing the biomechanical property of tissues. Our preliminary study on MRE in the normal human brain is described in this paper.

Material and Methods

The principle of MRE was given by MUTHUPILLAI et al. (7), and an external force actuator was developed. The actuator is an electromechanical device with a moving coil and an imager providing the static magnetic field. The actuator is fixed to the head coil. A wave generator produces a sinusoidal signal at low frequency, which is amplified to drive the actuator to apply transverse oscillation. During the scan, one side of the actuator is attached to the volunteer's head by a bite plate held in the teeth of the volunteer. Oscillation is generated by the actuator, which produces propagating shear waves at low frequency in the brain tissue.

A modified phase-contrast gradient-echo sequence was developed with motion-sensitizing gradients (MSG) (Fig. 1). MSG was synchronized to the external oscillation of the actuator using trigger pulses provided by the imager. In the presence of MSG, cyclic displacement within the brain tissue induced by shear waves causes a measurable phase shift in the received MR signal. The propagating shear waves within the brain are then directly imaged. By gradually increasing the

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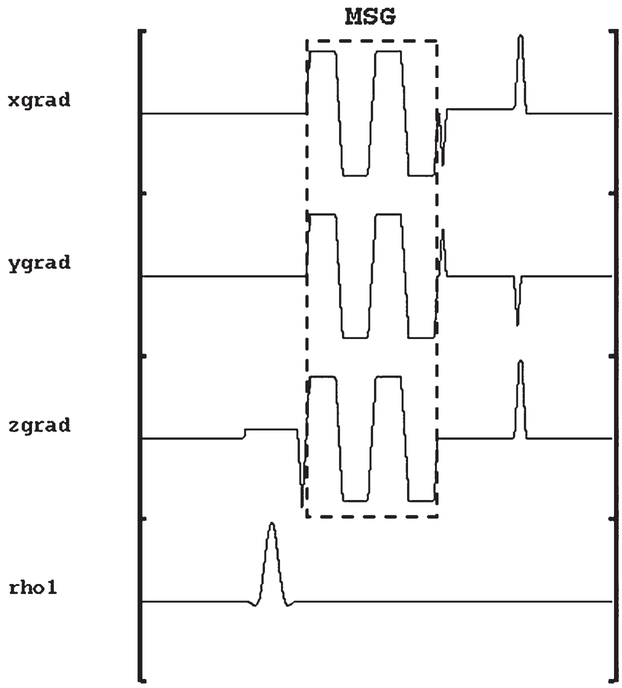

Fig. 1. Schematic diagram shows phase-contrast gradient-echo MR imaging sequence with motion-sensitizing gradients, which can be applied along any axis.

phase offset ($\frac{\pi}{4}$) between the external oscillation and MSG, eight images of shear-wave propagation can be obtained in one cycle.

The wave images of the brain are then processed to estimate the local wavelength at each location in the image using a technique known as local frequency estimation (LFE) (4). The shear modulus can be estimated by measuring the wavelength of the propagating waves according to the following equation:

$$\mu = \rho \cdot f^2 \cdot \gamma^2$$

where μ is the shear modulus, f is the frequency of the applied waves, γ is wavelength, and ρ is the density of the material. The density of the brain tissue is assumed to be equal to that of water (1.0 kg/m^3). Finally, the estimation of local wavelength was processed to compute a quantitative map of shear modulus.

In this study, MRE was performed with a 3.0T MR unit (GE Signa; GE Medical Systems, Milwaukee, Wisc., USA) with a gradient field strength of 40 mT/m, and a standard head coil was employed. Data acquisition parameters were: TR 51 ms, TE 17.8 ms, acquisition matrix 128×128, acquisition time 50 s, flip angle 30°, slice thickness 5 mm, FOV 24 cm. Shear waves at frequencies of 100 Hz, 150 Hz, and 200 Hz were applied. Axial images were acquired from three healthy male volunteers, ranging in age from 28–32 years.

Results

The propagating shear waves in the brain were clearly visualized on wave images. The direction of shear-wave propagation was from the surface of the brain to the center. The difference in wavelength of shear waves between gray and white matter of the brain was identified. The wavelength of shear waves in gray matter was shorter than that in white matter. The wavelength varied with the change of exciting frequency (Fig. 2). The propagation of shear waves in a wave cycle could be directly visualized in a dynamic fashion by viewing eight wave images acquired at gradually increasing phase offsets (Fig. 3). The elasticity image revealed the difference in tissue elasticity between gray and white matter of the brain: the elastic modulus of white matter was higher than that of gray matter (Fig. 4).

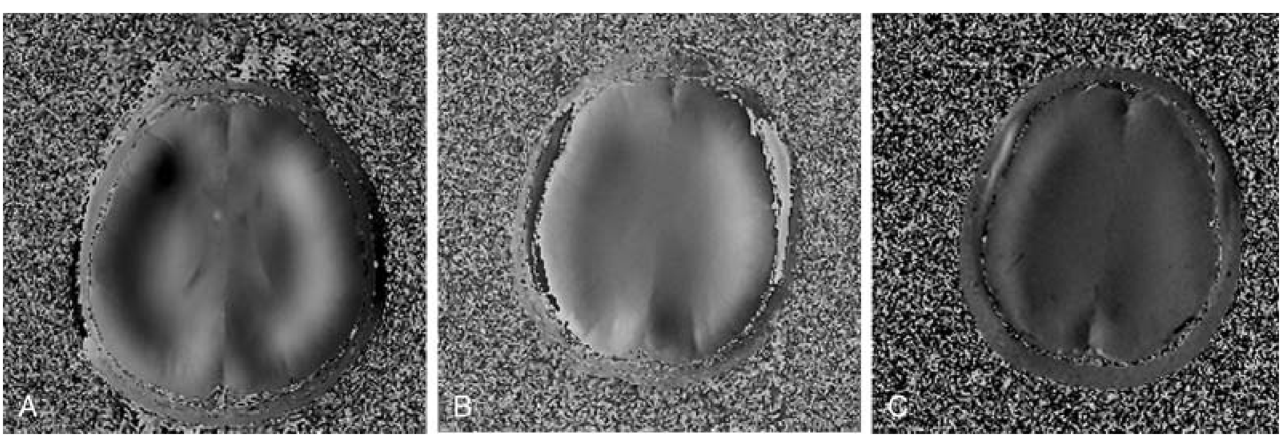

Fig. 2. Axial view of wave images shows the variation of wavelength with change in exciting frequency. A. 100 Hz. B. 150 Hz. C. 200 Hz.

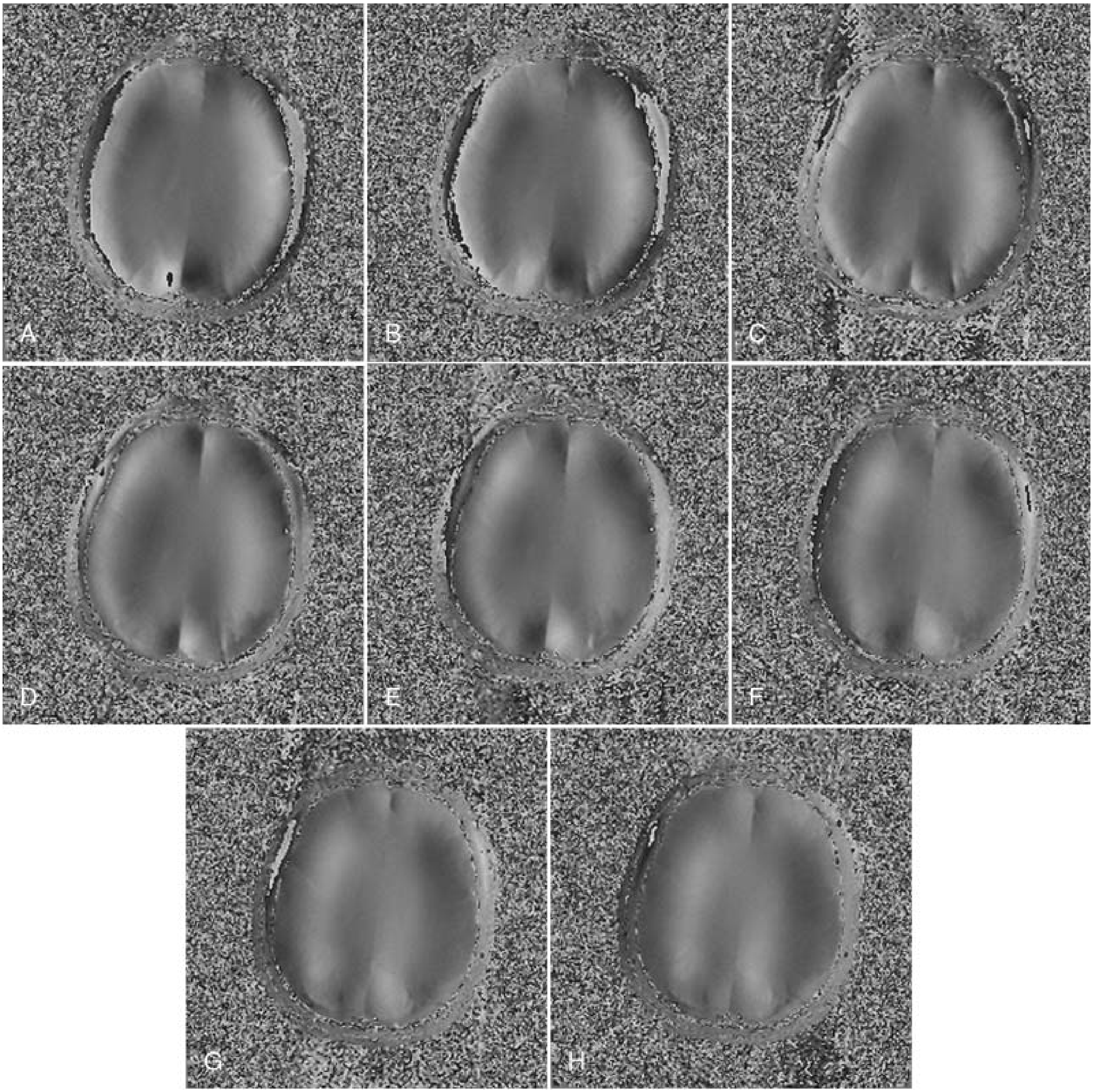

Fig. 3. Eight wave images (A–H) show the dynamic propagation of shear waves in a cycle (phase offset $\frac{\pi}{4}$ between each image, frequency 150 Hz) within the brain. The direction of shear-wave propagation was from the surface of the brain to the center.

Discussion

The elastic moduli of various human tissues are known to vary over a much wider range than other physical properties such as X-ray absorption or MR relaxation time (3). The elastic modulus of breast carcinoma specimens has been reported to be five- to 20-fold higher than that of adipose-glandular tissue and fibroadenoma specimens, using laboratory mechanical testing (2). The purpose of this study was to provide a new noninvasive imaging modality for evaluating biomechanical properties of intracranial tissues.

A suitable frequency of shear waves for MRE is from 50 Hz to 1000 Hz (5, 8). In our study, the suitable frequency of shear waves for imaging the brain was between 100 Hz and 200 Hz. The wavelength of shear waves was too long in comparison to the brain at frequencies below 100 Hz, and the attenuation of shear waves at frequencies above 200 Hz became evident. The propagation of shear waves at three different

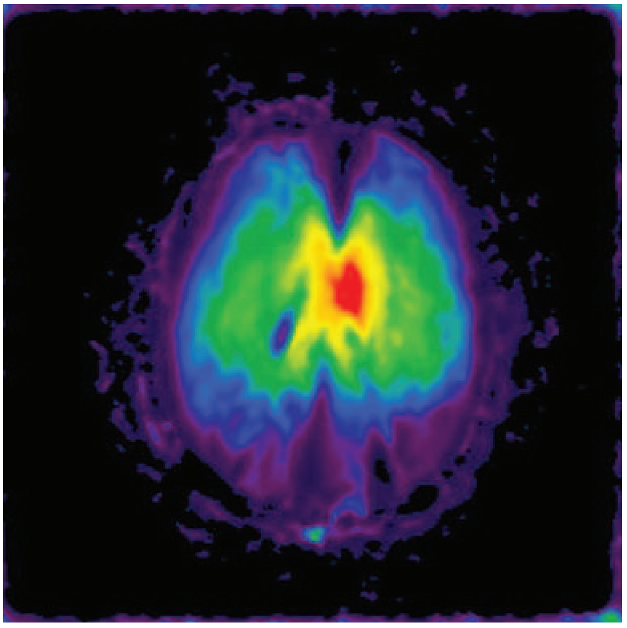

Fig. 4. Elasticity image shows the difference in elastic modulus between the white and gray matter of the brain (processed with local frequency estimation technique from imaging data in Fig. 2B).

frequencies within the brain was clearly visualized on wave images. The wavelength of shear waves varied with the change of frequency.

An effective imaging processing method must be adopted to realize the accurate estimation of tissue elasticity. LFE yields accurate local frequency estimates and is relatively insensitive to noise. Although a variety of imaging processing approaches has been used, it remains a challenge to obtain accurate elastography at high resolution. In this study, the LFE data-processing method was used to compute the elastic modulus, and the acquired elasticity images clearly demonstrated the difference in elasticity between gray and white matter of the brain.

In conclusion, MRE is a promising technique for differential diagnosis of intracranial lesions and for assessing the stiffness of a number of intracranial tumors before operation. This study was our preliminary application of MRE in the human brain in vivo with modest success. This technique still requires further improvement, and a series of clinical studies should be implemented on the basis of this imaging modality.

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