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Magnetic Resonance Elastography with Twin Drivers for High Homogeneity and Sensitivity

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Abstract—**Magnetic Resonance Elastography (MRE) is a phase-contrast technique using conventional Magnetic Resonance Imaging system to visualize propagating shear waves and study the stiffness of tissues. Usually, shear vibrations are applied to the surface of tissues by means of mechanical driver at one point. But it is hard for the single driver to detect very small tumors. Multiple drivers are expected to provide better elastogram and to be more sensitive to the small stiff inclusions. In this study, a pair of drivers was used and compared with the single driver. The result shows that using the twin drivers is more sensitive to small hard inclusions than using single driver. It is expected that the twin drivers can detect small tumors in tissues which can hardly be detected by a single driver. Further study will be conducted with the twin drivers in ex-vivo and in-vivo studies.**

Keywords—MR Elastography; shear wave; multiple drivers; stiffness

I. Introduction

Magnetic Resonance Elastography (MRE) is a phase-contrast technique to visualize propagating shear waves and study the shear properties (shear modulus, viscosity) of tissue [1]. Typically, the excitation wave is produced by a single driver placed at one point on the surface of the object. Recently, Mariappan et al. shows that the multiple drivers can provide better elastogram compared with single driver [2, 3]. In their experiment, eight drivers were put symmetrically on the phantom, and were driven simultaneously using 8-channel analog output; whereas the single wave image was obtained from one of the eight drivers driving individually. Multiple drivers are shown to be better than single driver because the former can provide completely illumination of the whole region of interest (ROI). In some applications, it is hard for a single driver to detect small tumors which are stiffer than background tissues, even though the single driver is able to provide adequate illumination. In our experiment, we use two drivers driven by the same source but placed at two different locations on the surface of the object. The purpose of this study is to determine whether the twin drivers have better performance in detection of small stiff inclusions in phantom by comparing elastograms with that produced by a single driver.

II. Theory

The propagation of an acoustic wave in a locally homogeneous isotropic viscoelastic medium is described by the following partial differential equation (PDE) [4]

$$\rho\partial_t^2\vec{u} = \mu\nabla^2\vec{u} + (\lambda+\mu)\nabla(\nabla\vec{u}) + \varsigma\partial_t\nabla^2\vec{u} + (\xi+\varsigma)\partial_t\nabla(\nabla\vec{u}) \tag{1}$$

where u denotes the displacement vector u(x, t), ρ is the density of the material (which is taken as constant and equal to water, 1.0g/cm^3), μ is the shear modulus, λ is the second Lamé coefficient, ζ is the shear viscosity accounting for attenuation within the medium, and ξ is the viscosity of the compressional wave.

In considering shear waves only, we apply the curl-operator to (1), and the equation becomes:

$$-\rho\omega^2\vec{q} = \mu\nabla^2\vec{q} + i\omega\varsigma\nabla^2\vec{q}, \vec{q} = \nabla\times\vec{u}, \vec{q}\in C^3. \tag{2}$$

There are only two unknown parameters in the above equation: μ the shear modulus and ζ the shear viscosity.

III. Material And Methods

A. Twin Drivers

The electromechanical driver consists of an electrical coil that generates motion to the rod attached. Alternating current was applied to the coil via a signal generator and power amplifier, and was triggered by the pulse sequence. This current created a magnetic field orthogonal to the main magnetic field, resulting in vertical oscillating motion of the rod. The other end of rod was attached to a plate with two contact points placed symmetrically. Vertical motion was transmitted to the contact points simultaneously and caused shear waves to propagate through the phantom. Fig. 1 shows the configuration of the twin drivers set.

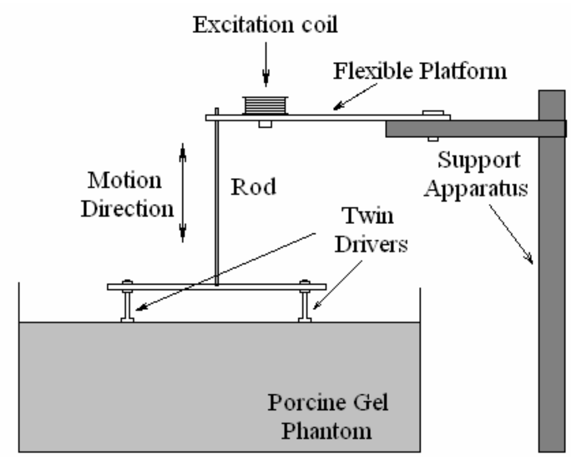

Fig. 1. The configuration of the twin drivers set

B. Porcine Gel Phantom

A cylindrical gel phantom of 19 cm diameter and 4.2 cm height was made with 11% porcine powder. Three cylindrical 14% porcine gels of diameters 2.3 cm, 1.1 cm, and 0.8 cm respectively were included in the phantom, and three cylindrical 8% porcine gels of diameters of the same dimensions were also included.

Fig. 2 shows the schematic of the gel phantom and the locations of the twin drivers. Left three inclusions (14% porcine powder) are stiffer than background matrix (11% porcine powder) and right three inclusions (8% porcine powder) are softer. The red dots represent the locations of the twin drivers.

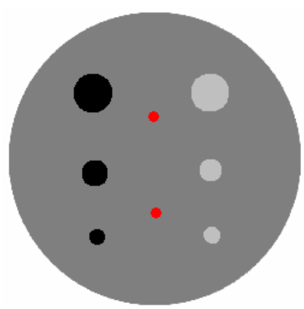

Fig. 2. Schematic of the gel phantom

C. Phantom measurement

Images were obtained on a Philips Intera Achieva whole body imager operated at 3.0 Tesla using a large SENSE Flex coil. The MRE pulse sequence was a motion sensitized (using sinusoidal displacement encoding gradients) spin echo sequence, phase-locked to the mechanical excitation. Seven slices (Slice Thickness= 2 mm) through the phantom were acquired. The field-of-view (FOV) was 192 mm; and the matrix size was 96^2 leading to an isotropic voxel size of 2 mm in all three directions. When excitation frequency of driver is 100Hz, eight dynamics images were measured with TE/TR= 40ms/490ms, leading to an acquisition time of 127 s to obtain one component of the displacement.

By estimating the wavelength of the shear waves from the acquired MRE images, the shear modulus was calculated by means of Helmholtz-Hodge decomposition [5].

IV. RESULTS

Fig. 3 shows the wave pattern images at 100Hz excitations generated by the twin drivers and single driver respectively. From these wave images, the phantom is completely illuminated in both the twin drivers and the single driver cases. But the wave patterns are different. The twin drivers generate interference pattern of waves.

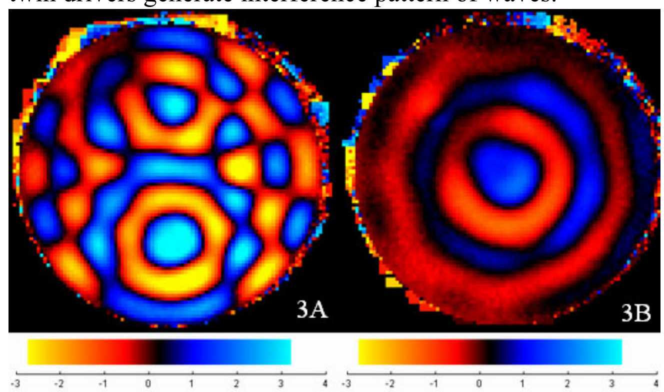

Fig. 3. A single wave image obtained from the twin drivers (A) and from the single driver (B)

Fig. 4 shows the comparison of inclusions detected by two kinds of drivers within the phantom. The black circles represent the boundaries of six inclusions from anatomical image. Because the wavelength in soft inclusions is shorter than it is in hard inclusions [6], it is more difficult to locate the hard inclusions. The smallest stiffer inclusions (Φ: 8 mm. 14% porcine powder gel) cannot be detected by the single driver but can be detected by the twin drivers driven at the same frequency (100Hz) and the same power input. The shape and the position of the inclusions in twin drivers case match the anatomical image. The artifacts along the boundaries in the single driver case are more serious than those in the twin drivers.

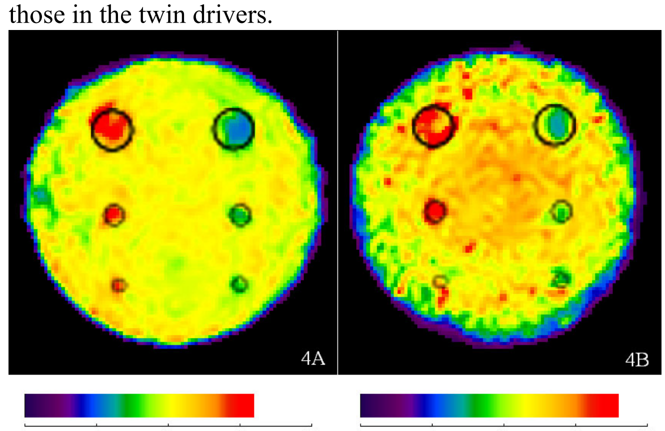

Fig. 4. Inclusions comparison. Elastograms from the twin drivers (A) and from the single driver (B).

The boundaries of the inclusion bodies were found to be better visualized and sharper in the twin drivers case than in the single driver case as shown in the elastograms of coronal images (Fig. 5.).

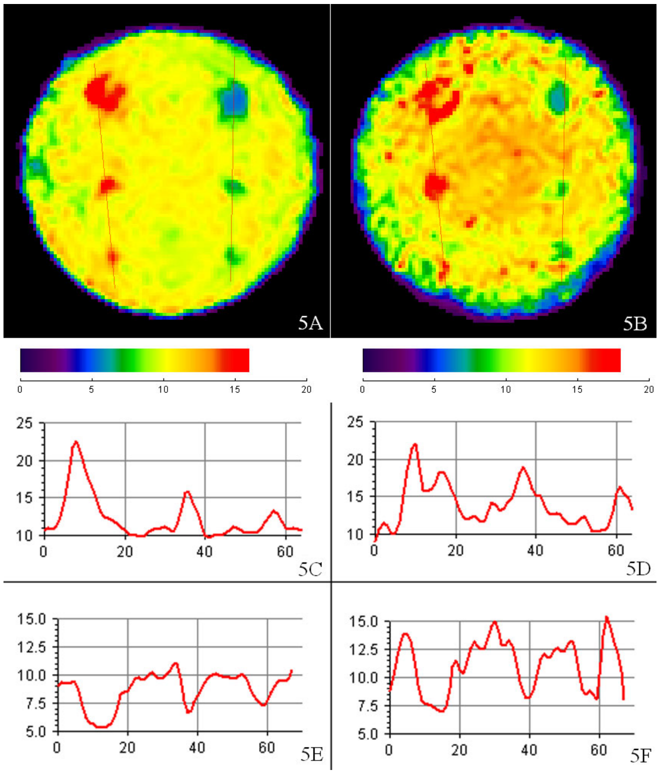

Fig. 5. Elastogram of coronal images by the twin drivers case (A) and the single driver case (B); the profile of stiffness on the hard inclusions (right red line) of Fig. 5A. (C) and profile of Fig. 5B. (D); the profile on the soft inclusions (left red line) of Fig. 5A. (E) and profile of Fig. 5B. (F).

In a separate experiment, the stiffness values of pure 8%, 11%, 14% porcine gel phantoms were measured by the twin drivers and single driver respectively in order to provide the reference stiffness values of the background (11% porcine powder) and the inclusion bodies (8% and 14% porcine powder). The mean and standard deviation of the stiffness estimates in the background and the inclusion bodies were calculated and compared between twin drivers case and the single driver case. From Table 1, it was found that the mean stiffness calculated from twin drivers dataset gave the closer match to the reference stiffness values; though due to the effect of the boundaries between the inclusions and the background to the propagation of the wave, the stiffness values calculated from the phantom with inclusions are different from the pure phantoms. Because the wave patterns generated by the twin drivers and the single driver are different, there are some margins between the stiffness values of the twin drivers and the single driver case.

Table 1: Mean stiffness calculated from the elastograms

	Stiffness Value Mean ± Standard Deviation (kPa)		
	Soft Inclusions	Background Matrix	Stiff Inclusions
Twin Drivers	7.524±0.310	10.099±0.090	14.037±0.570
Single Driver	8.811±0.503	12.139±0.642	16.807±0.637
Reference (Twin Drivers)	6.234	7.449	12.164
Reference (Single Driver)	6.294	7.838	12.451

V. Discussion And Conclusion

The results confirm that better elastograms can be provided by using the twin drivers as compared to the single driver case when both of them can completely illuminate the whole phantom. Mariappan et al. were the first to show that the multiple drivers can provide better elastogram compared with single driver. Their reason is due to the fact that the whole phantom was non-uniformly illuminated in the single driver case whereas it was wholly illuminated in the multiple drivers case by putting eight drivers symmetrically on the phantom [2, 3]. In this study, however, the whole phantom was completely illuminated in both the twin drivers and single driver cases. The interference pattern of waves generated by the twin drivers increases the sensitivity of detecting small objects. Using only two drivers simultaneously, the twin drivers case was shown to be more sensitive to small and hard inclusions. Under the same frequency and the same power input, the twin drivers could detect the smallest (Φ: 8mm) and stiffer inclusion with the right shape and at the right position whereas the single driver case couldn't. The elastogram of the phantom is more homogeneous and has fewer artifacts along the boundaries in twin drivers case. From the comparisons of shape and position of inclusions with anatomical images, sharpness of inclusions boundaries and the matches of stiffness values with references, there is a significant improvement in elastograms in the twin drivers, considering the conditions that the excitation frequency, voltage, and acquisition time are the same in both cases.

In conclusion, it appears that the twin drivers can be used to detect small tumors in tissues because it is more sensitive to the small and stiffer inclusions than the single driver. Further study is planned to use the twin drivers in ex-vivo and in-vivo studies.

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