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Shear waves induced by moving needle in MR Elastography

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Abstract—Magnetic Resonance Elastography (MRE) is a phase contrast-based method for observing shear wave propagation in a material to determine its stiffness. The objective of this study was to determine whether shear waves suitable for MRE can be induced using a moving acupuncture needle. Tissue-simulating bovine gel phantom and a 0.4mm diameter acupuncture needle were used in the experiment. The results showed that observable shear waves could be induced in the gel phantom by cyclic needle motion. The observed wavelength varied with excitation frequency, as expected. Generating shear waves using moving needles may be a useful tool to study the basic mechanism of acupuncture with MRE. Further study will be conducted to observe the wave motion in inhomogeneous media and acupuncture-induced effects in vivo studies.

Keywords—Acupuncture, MR Elastography, shear wave, stiffness

I. INTRODUCTION

Magnetic Resonance Elastography (MRE) is a phase contrast method used for quantitatively assessing the mechanical properties of tissue [1, 2]. A mechanical actuator coupled to the tissue provides cyclic motion synchronized to the imaging sequence. Most previous studies have applied mechanical motion at the surface of the tissue [1-5]. Recently, Rossman et al. showed that longitudinal motion of a carbon fiber rod inserted into a 2% agarose gel phantom can generate shear waves [6]. The longitudinal motion (motion in the direction of the rod's length) was produced by a piezoelectric bending element. We hypothesize that it may be possible to study the basic mechanism of acupuncture in vivo using MRE by inserting acupuncture needles into muscle tissue. The purpose of this study was to determine whether or not shear waves could be produced in a phantom by longitudinal motion of an acupuncture needle.

II. METHODOLOGY

Fig. 1 depicts how the piezoelectric bending element is configured to produce longitudinal motion of the needle. The needle was 0.4mm diameter and 50mm long. Tissue-simulating bovine gel phantom (15% bovine powder, approximately 225 bloom) was used in the experiment for observing the shear waves generated. MRE uses a modified

phase-contrast MRI technique to image induced shear waves as they propagate through the phantom. In addition to standard MRI imaging gradients, the MRE sequence incorporates oscillating, motion sensitizing field gradients that are synchronized to the frequency of the propagating waves. Data acquisition parameters were: TR 100ms, TE min full, flip angle of 30°, 256x64 acquisition matrix using a 16cm axial field of view. The acquisition time for each scan was 76.8s. The excitation frequencies were 50Hz, 100Hz and 200Hz. The shear stiffness was calculated using the following equation:

$$\mu = \rho f^2 \lambda^2 \quad (1)$$

where ρ is the density of the material, f is the excitation frequency and λ is the shear wave wavelength determined from the wave images. The density ρ is assumed to be 1.0g/cm³, which is appropriate for tissue-equivalent gels [7].

III. RESULTS

Fig. 2, 3, and 4 show the wave images at 50Hz, 100Hz and 200Hz excitations respectively. Longitudinal motion of the acupuncture needle induced the shear waves in the gel phantom. As the excitation frequency increased, the wavelength of the shear waves decreased. Few image artifacts were observed near the needle.

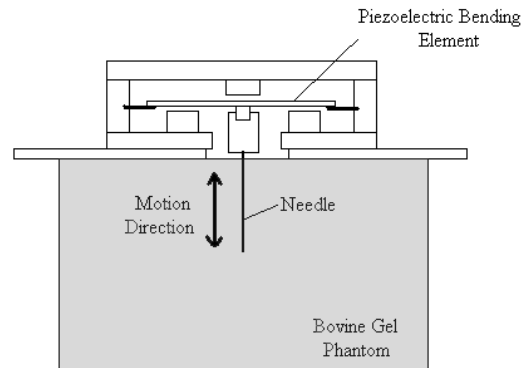


Fig. 1. The configuration of the piezoelectric driver

The shear stiffness estimated from the wave images and the standard deviation of the shear stiffness in the gel phantom at 50Hz, 100Hz and 200Hz are summarized in Table I.

IV. DISCUSSION

It has been shown that shear waves can be induced in vitro by rods, point sources or rectangular planes [1-6]. The size of these wave sources is larger than 100mmx100mm. In this study, shear waves were generated in a bovine gel phantom using a 0.4mm diameter acupuncture needle. To the best of our knowledge, no previous reports are found that shear waves can be induced by a fine and sharp needle.

As the excitation frequency increases from 50Hz to 200Hz, the wavelength in the gel phantom decreases. This phenomenon agrees with the wave propagation properties. The wavelength at 50Hz excitation frequency cannot be measured from the wave image, as the wavelength was longer than the width of the gel phantom. If the gel phantom is replaced by selected muscle group in vivo, the waves will propagate along the muscle length. The wavelength at low frequencies may be more readily measured in vivo, as they will be comparatively longer. Shear waves induced by a moving acupuncture needle can directly apply to the region of interest deeply embedded inside the object. Using the acupuncture needle to generate the shear waves may be suitable for the study at arm and leg muscles since the propagation direction of the waves is parallel to the muscle fiber direction.

In bovine gels the viscosity is a function of the excitation frequency [8]. The shear stiffness values at different excitation frequencies were not the same due to the dispersive nature of bovine gel phantoms. Further study is planned to observe the wave motion inside an in vitro bovine muscle specimen.

Table I
Shear stiffness estimated and standard deviation

<i>Excitation Frequency</i>	<i>Shear stiffness</i>	<i>Standard deviation</i>
50Hz	11.388kPa	3.914
100Hz	7.505kPa	1.573
200Hz	9.251kPa	2.015

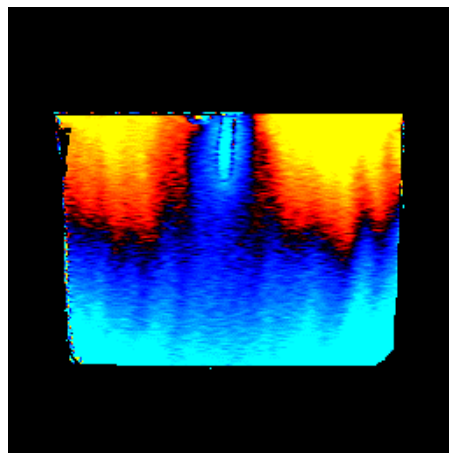


Fig. 2. Wave image at 50Hz excitation

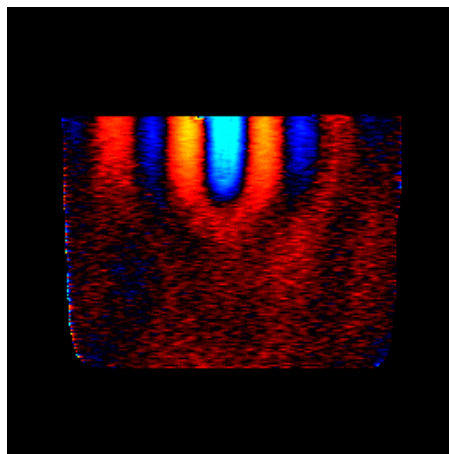


Fig. 3. Wave image at 100Hz excitation

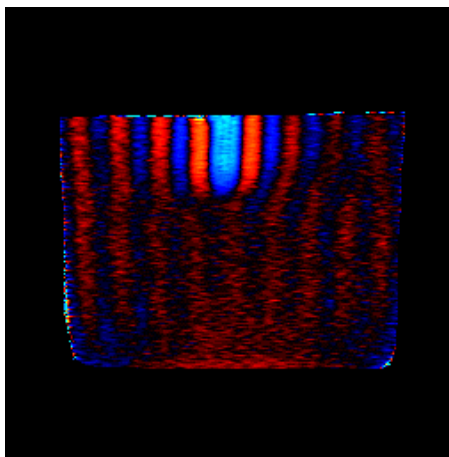


Fig. 4. Wave image at 200Hz excitation

V. CONCLUSION

The experimental results show that it is possible to generate propagating waves using a moving acupuncture needle and observe the phenomenon with MRE. In previous works, in vivo studies were limited to shear waves generated at the surface of the tissue [1-5]. A disadvantage of this approach is that shear waves can be heavily attenuated by tissue on the surface, and can have difficulties reaching deeper structures of interest. By inserting the needle into the muscle, the shear waves will be applied directly to the muscle of interest. It appears that the induced waves by a moving needle can be used to study the mechanism of acupuncture in vivo with MRE. The physical acupuncture treatment can be simulated by moving the needle up and down (in and out) at a specific acupoint. Further study will be conducted to verify the use of moving needle in an in vivo study.

ACKNOWLEDGMENT

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