Focused Acoustic Driver to Generate High-Frequency Shear Waves in Deep Regions for Magnetic Resonance Elastography

M. Suga[1,2], T. Obata[2], M. Sekine[3], M. Hirano[4], H. Miura[1], K. Arai[1], S. Ozawa[1], and H. Ikehira[2]
[1]Graduate School of Technology, Chiba University, Chiba, Chiba, Japan, [2]Molecular Imaging Center, National Institute of Radiological Sciences, Chiba, Chiba, Japan, [3]Research Center for Frontier Medical Engineering, Chiba University, Japan, [4]GE Healthcare Japan, Tokyo, Japan

INTRODUCTION

Magnetic resonance elastography (MRE) is a phase-contrast technique that can noninvasively visualize shear waves patterns within tissue [1]. Accurate values of tissue stiffness are calculated by the equations of motion from the shear wave pattern of a single frequency [2]. In order to generate shear waves within tissue, various external drivers have been proposed [3]. To acquire an accurate shear modulus map (defined as an elastogram) in high spatial resolution in deep regions, external drivers must generate a precisely controlled high frequency (higher than 100 Hz) and a large amplitude vibration. Also, for clinical use, drivers tend to be of a simple and robust design. Currently, there are no drivers that satisfy all these conditions. For example, electromechanical and pneumatic approaches demonstrate the feasibility of applying MRE to deep-lying organs, although these drivers cannot match the precise control of a piezoelectric actuator in terms of frequency, amplitude and phase. Whereas small displacements are a drawback in piezoelectric materials, and the need for mechanical amplification increases the design complexity [4]. In this study, we develop a simple and robustly designed focused acoustic driver to enhance shear wave amplitude in deep regions by high frequency using a piezoelectric actuator. To confirm the performance of the proposed driver, phantom studies are performed.

MATERIALS AND METHODS

The proposed focused acoustic driver consists of multiple actuators. The heads of the actuators are arranged on a concave spherical surface. The driver comprises nine (3 x 3) multilayer piezoelectric actuators (NEC TOKIN Corp.; width: 3 mm x depth: 2 mm x height: 40 mm, 200 N) made of acrylic plastic materials, as shown in Fig. 1. The piezoelectric actuators are exposed to the subject through small acrylic blocks with a width of 5 mm, depth of 5 mm and height of 10 mm. The piezoelectric actuators are driven by a waveform generator, which is synchronized with an MR controller using a trigger pulse. The amplitude of vibration at the surface of the subject is about 20 μm.

Experiments were performed using a GE Signa HDx 3.0T. A modified phase-sensitive spin-echo EPI sequence was used for data acquisition. Oscillating gradients (motion-sensitizing gradients, MSG) were synchronized by mechanical excitation to encode shear waves. Shear wave images with multiple initial phase offsets were generated with increasing delays between MSG and mechanical excitation. In order to acquire the elastogram, we applied an inversion algorithm using a three-dimensional integral-type reconstruction formula to the shear wave images with four phase offsets.

The object was a tissue-simulating gel object, 15.8 kPa homogeneous polyacrylamide (PAAm) gel phantom. Dimensionally, the object was a rectangular parallelepiped with a width of 125 mm, depth of 135 mm and height of 55 mm. The MRE imaging protocols were: single-shot EPI, repetition times (TR) = 2000 ms, echo time (TE) = 31.5 ms, field of view =128 × 128 mm^2, image matrix = 64 × 64, slice thickness = 2 mm, number of slices = 11, number of excitations = 1, MSG cycles = 3, phase offsets = 4 and mechanical vibration frequency = 250 Hz.

To confirm the performance of the driver, the signal-to-noise ratio (SNR) of the induced shear waves and the accuracy of estimated shear modulus was compared with a nonfocused acoustic driver, single piezoelectric actuator (NEC TOKIN Corp.; width: 10 mm x depth: 10 mm x height: 40 mm, 3500 N) with an acrylic block (width: 15 mm x depth: 15 mm x height: 10 mm), and the focused acoustic driver.

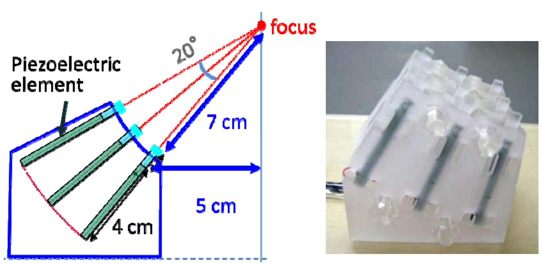

Fig. 1 Focused acoustic driver comprising nine (3 x 3) multilayer piezoelectric actuators (green rods).

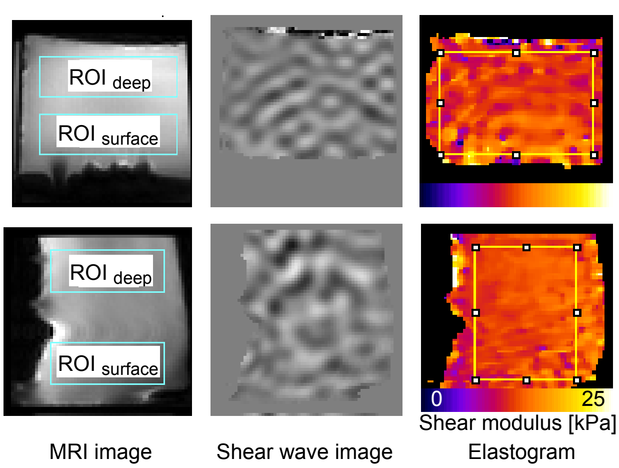

Fig. 2 MRI image, shear wave image (250 Hz) and elastogram of the PAAm gel phantom.
Upper row: using nonfocused acoustic driver
Lower row: using focused acoustic driver

RESULTS

Figure 2 shows an MRI image, shear wave image and elastogram of the 15.8 kPa homogeneous PAAm gel phantom. A more quantitative result of these differences is presented in Fig. 3. The SNR of the shear wave image is highest in the deep region using the focused acoustic driver. Estimated shear modulus using the nonfocused and focused acoustic driver are 12.1 (s.d.=1.9) kPa and 12.4 (s.d.=1.1) kPa, respectively.

CONCLUSION

In this study, we proposed a simple and robustly design focused acoustic driver to generate high-frequency shear waves in deep regions. From the results of the experimental studies, it was shown that the focused acoustic driver increases the SNR of the shear wave image in the deep region and improves shear modulus quantitatively. These results suggest that the proposed driver will enable accurate measurement of the shear modulus at a high spatial resolution in deep regions.

REFERENCES

[1] Muthupillai R., et.al. *Science*, 269:1854-1857, 1995.
[2] Manduca A., et.al. *Med. Image Anal.*; 5 (4): 237–254, 2001.
[3] Uffmann K., et.al. *IEEE EMBM*, 27 (3): 28-34, 2008.
[4] Tse ZT, et al., *Proc Inst Mech Eng H*, 223: 497-514, 2009.

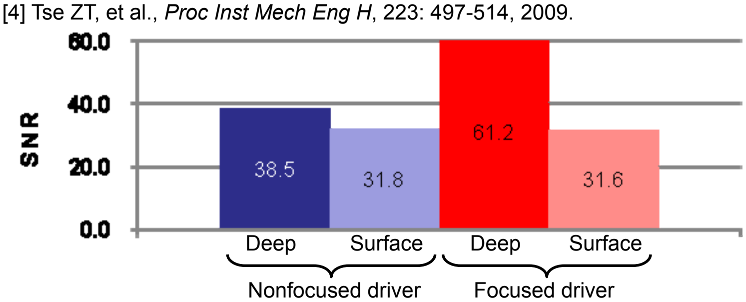

Fig. 3 Signal-to-noise ratio at deep and surface region of shear wave images as shown in Fig. 2.