Passive Array Mechanical Driver for Magnetic Resonance Elastography of the Breast

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Introduction. Dynamic magnetic resonance elastography (MRE) is a method for quantitatively imaging the mechanical properties of tissue, using modified phase-contrast MRI to visualize applied shear waves [1]. There is interest in exploring possible applications of MRE in the diagnosis of breast cancer, where the technique might be used as an adjunct to contrast-enhanced MRI. Several groups are currently working to develop implementations that will have sufficient reliability to allow clinical trials to be conducted to test the capacity of MRE to aid the characterization of enhancing breast lesions [2, 3]. These efforts have focused on developing optimized pulse sequences for rapidly and sensitively imaging the applied shear waves, and developing mathematical inversion techniques to reliably compute the local mechanical properties of tissue from the wave images. A third challenge is to develop suitable methods of applying mechanical waves during breast MRI. The approach to date has been to design a special breast MRI coil that also contains mechanical drivers [4]. The disadvantage of this approach is that the imaging performance of the special-purpose combined device may be inferior to the latest commercial multichannel breast MRI coils. This creates difficulties in accruing patients to a trial of MRE-assisted breast MRI, because the contrast-enhanced breast images obtained with the combined device may be inferior to what can be obtained with a state-of-the-art breast RF coil system. An approach that could eliminate this problem would be to develop a mechanical driver device that can be used in combination with any standard breast RF coil system. In this report, we describe our progress towards that goal.

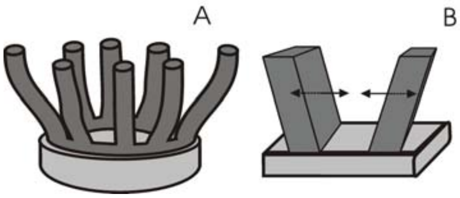

Fig.1
Schematic of the setup utilizing:
A) – tubular array driver;
B) – drum-like driver.

Materials and Methods. While active driver devices such as electromechanical and piezoelectric actuators have been successfully used in MRE, their size and tendency to create local artifacts make them unsuitable for use in this application. Our previous work with "pressure activated drivers" showed that a local slave actuator, connected by a flexible conduit to a pneumatic driver located outside the bore of the imager, can be used to generate mechanical waves in the body inside the scanner [5]. The local driver, a simple drum-like device is entirely non-metallic and passive, so that there are not local artifacts. In other preliminary work, we determined that elastic tubing, coupled to the skin surface, can be used in place of the drum-like actuator for MRE studies of skeletal muscle [6]. Therefore, the design goal of this work was to develop and test a driver for breast MRE consisting of a thin, flexible mesh, containing an array of tubular passive pneumatic actuators, that can be interposed between the breast and the RF coil array. For initial testing of the concept, we developed a radial array of eight silicone tubes, aligned symmetrically in circle and coupled by a pneumatic conduit to an acousto-electromechanical driver located beside the imager (Fig. 1A). The shear wave performance of this device was compared to our current integrated breast MRI/MRE device, which contains two large passive actuators that apply mechanical waves to the medial and lateral aspects of the breast (Fig. 1B). Testing was performed using a semispherical, 12 cm in diameter, tissue-simulating (7% gelatin) breast phantom, containing two 2% agar cylindrical stiff inclusions. The diameter of inclusions was 10 mm and lengths were 25 mm and 15 mm. A 2D slice GRE MRE sequence (TR=125 ms, TE=32 ms, FOV=16 cm, 4 mm in thickness) was used to image the applied mechanical waves. Mechanical excitation frequency was 80 Hz, and 2 cycles of motion encoding gradients were applied along the x, y, and z directions in successive acquisitions.

Results. Figure 2 shows a magnitude image and wave images with motion sensitization in the x, y, and z directions, for a representative section of the breast phantom, obtained using the tubular array driver. Figure 3 shows an elastogram, obtained using all wave sensitizations and the Local Frequency Estimation algorithm [7]. Figure 4 shows measured shear stiffness along a profile line passing through both stiff inclusions. Figures 5-7 show the corresponding results obtained with the older combined driver/RF coil device.

Tubular array driver:

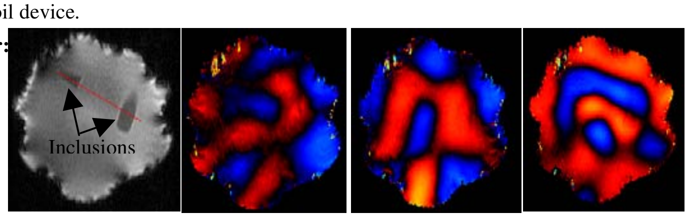

Fig. 2A **Magnitude image** | **Fig. 2B** **Motion in x-dir^n** | **Fig. 2C** **Motion in y-dir^n** | **Fig. 2D** **Motion in z-dir^n**

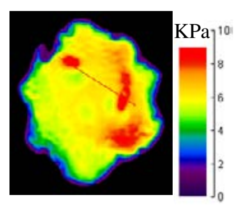

Fig. 3
Map of shear modulus

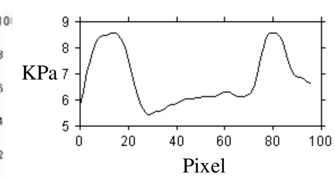

Fig. 4
Shear modulus along the red line

Drum-like driver:

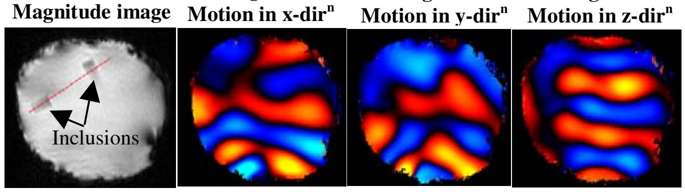

Fig. 5A **Magnitude image** | **Fig. 5B** **Motion in x-dir^n** | **Fig. 5C** **Motion in y-dir^n** | **Fig. 5C** **Motion in z-dir^n**

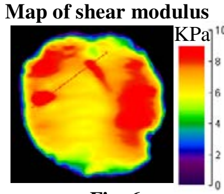

Fig. 6
Map of shear modulus

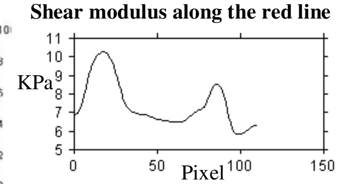

Fig. 7
Shear modulus along the red line

Discussion and Conclusions. The results of multiple phantom studies, as summarized in figures 2 to 4 demonstrate that the tubular array driver provides shear wave illumination throughout the breast phantom that is comparable in extent and somewhat more uniform than obtained with the combined driver/RF coil device. Shear wave data obtained with the tubular array driver provided quantitative elastograms that depicted the stiff inclusions similarly to the results obtained with the older combined device. The shear modulus of 7% bovine gel was estimated to be 6-7 KPa and the shear modulus of 2% agar inclusions was measured at 8-9 KPa, what is comparable to previously measured reference values [8]. The amplitude of shear waves generated with the prototype tubular array driver was lower than with the combined driver, but this can be addressed by optimizing the diameter and thickness of the passive driver tubes and by increasing the power of the active driver. These considerations are currently being incorporated into the next prototype. In conclusion, the results provide evidence for the feasibility of designing a simple mechanical wave driver for MRE of the breast that can be used with standard breast MRI RF coil systems.

References. [1] R. Muthupillai, D.J. Lomas, P.J. Rossman, J.F. Greenleaf, A. Manduca, R.L. Ehman. Science, 1995; 269:1854-1857;
[2] B.S. Garra, E.I. Cespedes, J. Ophir, S.R. Spratt, R.A. Zuurbier, C.M. Magnant, M.F. Pennanen. Radiology, 1997; 202 (1): 79-86;
[3] R. Sinkus, M. Tanter, T. Xydeas, S. Catheline, J. Bercoff, M. Fink. Magnetic Resonance Imaging, 2005; Sp. Iss. 23 (2): 159-165;
[4] T. Xydeas, K. Siegmann, R. Sinkus, U. Krainick-Strobel, S. Miller, C. D. Claussen, MD. Investigative Radiology, 2005, 7, 40: 412-420;
[5] M. Yin, O. Rouviere, R.L. Ehman. ISMRM, 13th Scientific Meeting and Exhibition, Miami, FL, 2005;
[6] S. F. Bensamoun, S.I. Ringleb, Q. Chen, T.C. Hulshizer, P.J. Rossman, R.L. Ehman, K-N. An. ISMRM, 13th Scientific Meeting and Exhibition, Miami, FL, 2005;
[7] H.Knutson, C-F. Westin, G. Granlund. Proceedings of IEEE International Conference on Image Processing, Austin, TX, November, 1994;
[8] S.I. Ringleb, Q. Chen, D.S. Lake, A. Manduca, R.L. Ehman, K-N. An. Magnetic Resonance in Medicine, 2005, 53: 1197-1201.