Magnetic Resonance Elastography with Multiple Drivers.

Y. Mariappan[1], P. J. Rossman[1], R. L. Ehman[1]
[1]Department of Radiology, Mayo clinic college of Medicine, Rochester, Minnesota, United States

Introduction:

Magnetic Resonance Elastography (MRE) uses a phase-contrast MR imaging technique to visualize propagating shear waves, in order to estimate the stiffness of tissue (1). The shear waves are typically produced by an electromechanical, pneumatic or piezoelectric driver, applied to the surface of the object. In some applications, we have found that the effects of attenuation and shadowing may not provide adequate illumination of a region of interest within an object for optimum wave imaging. To address these limitations, we developed and investigated a phased-array acoustic driver system capable of applying independently-controlled waveforms to each channel. We hypothesized that, by suitably adjusting the waveform applied to each driver in the phased array, it would be possible to optimize the acoustic illumination of any specified arbitrary region of interest (ROI) within an object. Furthermore, we hypothesized that the MRE wave-imaging technique provides a direct means of characterizing the phase relationship of a given driver and the response in the ROI, thereby streamlining the selection of a waveform for each driver channel.

Materials and Methods:

A 1.5 T whole body scanner(GE Signa, Milwaukee, WI) and Helmholtz surface coil were used for the experiments. A cylindrical gel phantom of 20 cm diameter and 7 cm height was made with 2% agar. A 4% agar gel of dimensions 2.5 cm × 2.5 cm × 7 cm was also included in the phantom. A setup of eight electromechanical drivers, with 2 Ω resistance in each coil, was placed in the phantom. All the eight drivers were driven simultaneously, by using a commercially available 8-channel 16 bit analog output board (PD2-AO-8/16). In a preliminary set of wave images, the response of the phantom to a waveform from each driver was measured. Given these response maps, waveforms for each of the drivers were derived to optimally illuminate selected test ROI's within the phantom. The effectiveness of the phased array illumination was then tested and compared with results obtained with single channel illumination and with non-optimized multi-channel illumination.

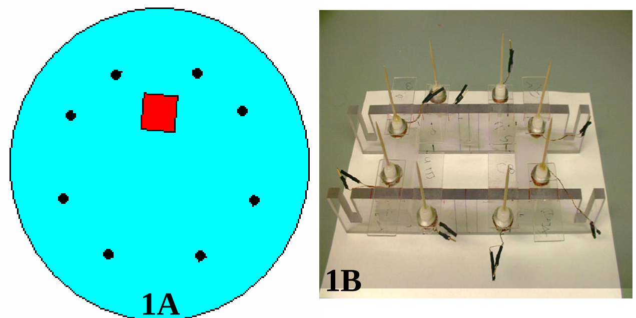
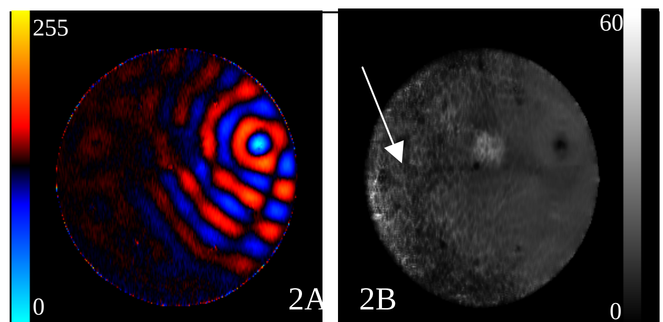


Fig 1. Schematic of the circular 2% agar gel phantom with the 4% agar square inclusion (A) and the eight driver setup used(B).

Results and Discussion:

Figs. 1A and 1B show the schematic of the gel phantom and the eight drivers set up used respectively. The positions of the eight drivers are shown as black dots and the hard, square inclusion is shown in red. A single wave image obtained from one of the drivers driving individually is shown in Fig. 2A. The driver shown here is at a distance which is the mean distance from the eight drivers to the center of the ROI. Local Frequency Estimation(LFE) algorithm(2) was used to calculate the relative stiffness estimate of the phantom and the corresponding elastogram for the single driver MRE data is shown in Fig 2B. The arrow in the Fig 2B. indicates artifacts, due to the non-uniform illumination of the region. Fig. 3A shows the MRE data with all the drivers generating the waves. The corresponding elastogram is shown in Fig. 3B. From these images, it is clear that the phantom is completely illuminated in the multiple drivers case (Fig. 3B) and this reduces the stiffness estimate artifacts present in the regions located away from the driver in the single driver dataset . Also, the boundaries of the inclusion body were found to be better visualized in the multiple drivers case. In a separate experiment on a 4% agar gel phantom of the same batch, the stiffness value was found to be 51 KPa. The mean and the standard deviation of the stiffness estimates in the square inclusion were calculated and compared for the single channel, non-optimized multi-channel and the optimized multi-channel data. In the non-optimized case, though there was a good illumination of the object, due to undetermined constructive and destructive interference patterns, the stiffness estimate was not good. It was found that the mean stiffness calculated from the phase-optimized multi-driver dataset gave the closest match to the reference stiffness value.



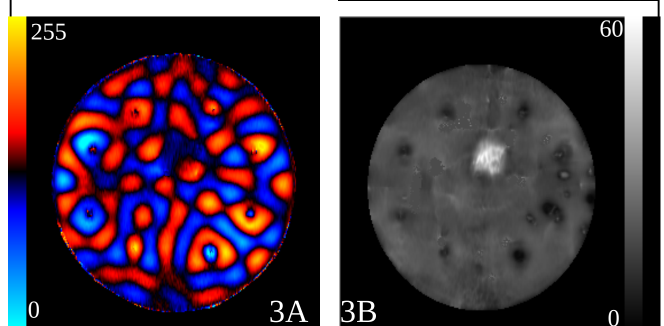


Fig 2. A single wave image obtained from a single driver (A), and the corresponding elastogram(B)

Fig 3. A single wave image of multiple driver MRE dataset phase optimized for the square inclusion(A) and the corresponding elastogram(B)

Table 1: Mean stiffness calculated from the elastograms

Source Elastogram	Stiffness Value Mean ± Standard deviation (KPa)
Single driver	44.316 ± 9.327
Eight drivers phase-optimized	54.143 ± 7.151

Conclusion:

The results confirm the hypothesis that a phased-array driver can provide improved shear wave illumination in a selected region, compared with a single driver or multiple non-independent drivers, resulting in an improved elastogram. This is a significant improvement considering the fact that the acquisition times are the same in each case.

Reference:

(1)R.Muthupillai, Science 1995, 269: 1789-1936;(2)A.Manduca, Med Image Anal. 2001 Dec;5(4):237-54.