# Shear Wave Tracking in Cadaveric Breast Using MR-ARFI

R R Bitton[1], E Kaye[2], and K Butts Pauly[1]
[1]Radiology, Stanford University, Stanford, CA, United States, [2]Electrical Engineering, Stanford University, Stanford, CA, United States

**Introduction**

Evaluation of mechanical properties in breast tissue has value, both as a diagnostic tool, and in treatment planning. Pathologic changes in the breast are often accompanied by changes in tissue stiffness [1]. Additionally, MRgHIFU lesions that create stiff ablation spots, could be used for pre-operative lesion marking of non-palpable tumors [2,3]. Acoustic Radiation Force Imaging (ARFI) is a technique that uses ultrasonic radiation force to induce a mechanical displacement of tissue, reporting on tissue velocity and elastic modulus. It has been used to measure liver stiffness with ultrasound imaging [4]. In contrast to other elastography methods, such as MRE, which use external mechanical vibrators to displace the tissue, MR-ARFI uses focused ultrasound to generate a radiation force at a smaller, targeted focal region. This study presents an MR-ARFI method that uses two ultrasonic excitations to image the extent of the shear wave, and calculate tissue velocities along radial trajectories. The first ultrasonic excitation is used to induce the shear wave to be tracked, and the second excitation is used as the focal reference point to measure the extent of the shear wave.

**Materials and Methods**

Experiments were performed in a GE 3T scanner using the InSightec ExAblate 2000 system with a solenoid breast coil. The MR-ARFI sequence was a 2DFT spin-echo (TE/TR = 56ms/500ms), with 4 ms unipolar displacement encoding gradients $G_{DE}$ applied along the ultrasound beam direction (Fig 1). Two ultrasound pulses (1MHz, 4ms, 90W acoustic, 0.8% duty cycle) are triggered on before the first $G_{DE}$. The time point of the first ultrasound pulse was varied while the second pulse was fixed in relation to $G_{DE}$. MR-ARFI displacement maps were constructed by subtracting the phase of images acquired with opposing polarity of $G_{DE}$.

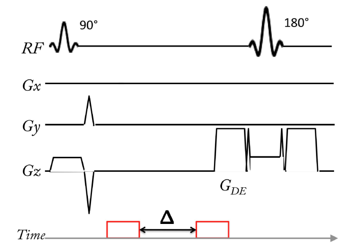


**Figure 1.** MR-ARFI using double ultrasonic excitation.

MR-ARFI maps were acquired in a uniform phantom for four increasing values of Δ (Fig 2a) for a combined scan time of 6.4 min. The maps visualize the extent of propagation of the shear wave induced by the first interrogation with respect to the second. Spatial extent was sampled using radial trajectories starting at the central interrogation and extending outwards by increments of θ. Contours representing the spatial location of the shear wave peak from the central interrogation were combined into a single plot, where color intensity indicates distance from central focus (Fig 2b). Using time-of-flight relationships, where distance to peak of shear wave is measured for points in time, Δ, for radial projection, θ; the best fit slope through the points is estimated shear wave velocity (Fig 2c). This method was applied to a non-preserved cadaveric breast specimen. First, a series of closely spaced heating ablations were used to create a sub-region of increased stiffness (21 ablations, 150W, 20s). Post ablation MR-ARFI interrogations (TE/TR = 56 ms/1s, 48W acoustic, 0.4% duty cycle) were prescribed adjacent to the ablated region for three values of Δ.

**Results**

MR-ARFI maps in the phantom show primarily radial shear wave propagation except towards left, at the boundary of the phantom (Fig 2b). Maps in the cadaveric breast show the central interrogation, and are able to capture the extent of shear wave from the initial interrogation (Fig 2d). Contour plots indicate the shear wave maxima at Δ = (8, 10, 12) ms. They show an increase in shear wave extent and a non-uniform propagation adjacent to the ablated region (Fig 2e). Velocity increases can be seen leading up to the ablated region, however the shear wave peak could not be identified directly in the ablated tissue (~θ=175-225). The velocity plot highlights the heterogeneity of breast tissue by showing variations in shear wave velocity, ranging from (0.4 – 6.3) m/s (Fig 2f).

**Discussion**

The lack of identifiable peak in the ablated region of the cadaveric breast may be due to reduced displacement, and greatly increased shear velocity, where the wave may have already propagated outside the field of view. Both instances are congruent with significantly increased stiffness compared to surrounding tissue. The low SNR of the MR-ARFI maps in tissue may have been due to the partially fragmented specimen. This issue may not be relevant *in vivo*, where more cohesive bulk tissue is a factor. Future work will include optimizing the spatial distribution of time samples, Δ. A key concern in the reduction of this parameter is the inherent tissue relaxation time: overlapping tissue responses from each interrogation could confound the results.

**Conclusion**

This study presented an MR-ARFI based method for shear wave velocity measurement using double ultrasonic interrogations. Measurements in cadaveric breast specimens tracked the extent of the shear wave around normal and ablated tissue. Estimated shear velocities in the breast were in agreement with the literature [5]. This technique may be a useful tool in mapping the stiffness of regions within heterogeneous tissue, such as the breast.

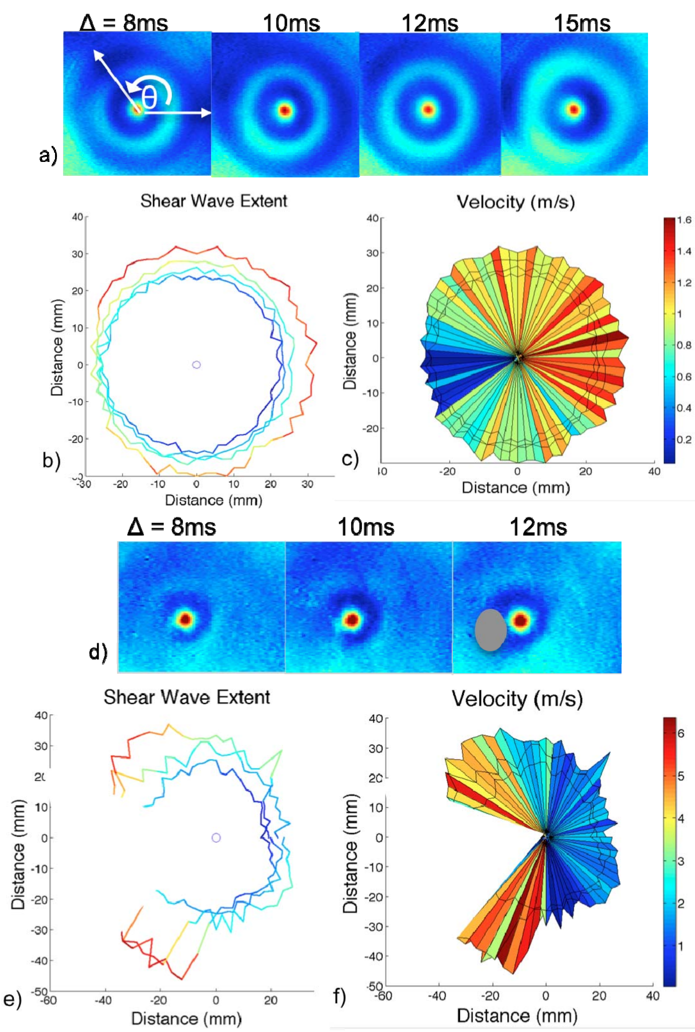


**Figure 2.** MR-ARFI displacement maps (a,d), Shear wave contours (b,e), and velocity (c,f) in a uniform phantom (top row) and cadaveric breast specimen (bottom row). Grey circle indicates ablated region.

**References**

[1] Sarvazyan AP, et al, U Med Biol. 1998 Nov;24(9):1419-35. [2] Schmitz AC, et al, JMRI 2009 Oct;30(4):884-9. [3] Bitton RB, et al, Proc ISMRM 2010;18. [4] Wang MH, et al, U Med Biol 2009 Oct;35(10):1709-21. [5]Garra BS, et al, Radiology 1997; 202: 79–86.

**Acknowledgements:** R21 EB011559, California Breast Cancer Research 16FB-0090.