Rapid FUS Focal Spot Localization based on MR-ARFI.

E. Kaye[1,2], J. Chen[1,2], and K. Butts Pauly[2]

[1]Electrical Engineering, Stanford University, Palo Alto, California, United States, [2]Radiology, Stanford University, Palo Alto, California, United States

Introduction

For various therapeutic applications, focused ultrasound (FUS) is used in either thermal mode or in mechanical mode. Mechanical mode FUS has been used for temporary blood brain barrier disruption and for targeted drug delivery. Monitoring of such treatments remains a technical challenge since there should be no significant temperature increase in the focal spot, unlike in case of thermal mode FUS. As a potential monitoring method, it has been proposed to use MR acoustic radiation force imaging (MR-ARFI) to measure tissue displacement in the focal spot, rather than temperature. To do this, the ultrasound is applied during motion sensitizing gradients, which encode the displacement induced by the acoustic radiation force into the phase of the image.

In previous work, the displacement maps were acquired with a diffusion-weighted (DW) line scan sequence,[1,2] and a set of repeated bipolar gradients were found to provide the optimal SNR and displacement sensitivity.[2] In this work, the repeated bipolar displacement encoding gradients are combined with a single shot EPI readout to localize the focal spot, while minimizing the scan time and possible heat deposition.

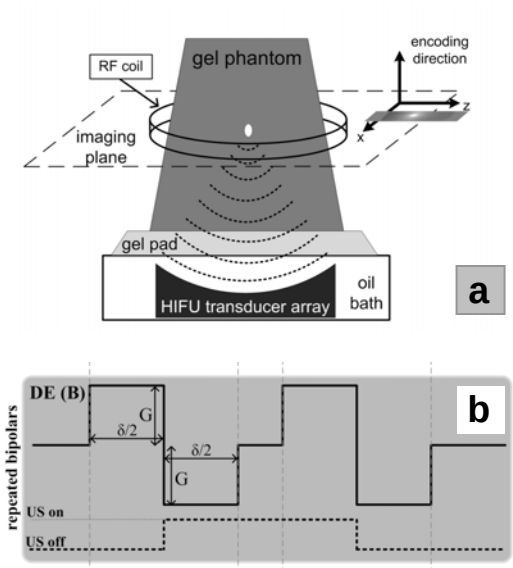

Figure 1. a. Experimental setup; **b**. Repeated bipolar gradients for displacement encoding.

Methods

A single shot DW flyback EPI pulse sequence was developed with a reduced FOV in phase-encode direction. A rectangular slab was excited by applying orthogonal slice select gradients for the 90° and 180° RF pulses. Imaging was performed on a 3T GE Signa MR scanner equipped with an MR-compatible FUS system (InSightec, Israel). Coronal plane images were obtained with the following parameters: TR/TE=139/100 ms, FOV=14.5x4cm, matrix size = 140x25, slice thickness 3mm, bandwidth = 62.5kHz, NEX=5. The b-value was 70 s/mm^2.

The experimental setup is shown in Fig.1a. An ultrasound gel phantom was placed above the FUS transducer with a gel pad in between. A solenoid RF coil was placed around the phantom. The MRI pulse sequence triggered the FUS system to emit ultrasound pulses of 80W at 1.0MHz. The US pulses were synchronized with the encoding gradients as shown in Fig.1b. The ultrasound beam was focused inside the gel phantom at a depth of 12cm.

To map displacement, a pair of images were obtained with identical imaging and sonication parameters, but with opposite polarity of the encoding gradients. Both images were corrected for bulk motion phase by subtracting constant and linear background phase. From these images a phase difference image was calculated and converted to displacement.

Results

Images obtained with the sequence are shown in Fig.2. Phase images acquired with the negative and positive polarities of the encoding gradients show similar background phase. The difference of these two images is shown in Fig.2c, with the focal spot of the displacement clearly recognizable. The displacement map image is shown on the scale [-0.1 0.1] radians. The estimated displacement value in the focal spot, ~0.5µm, agrees well with previously reported values acquired with the line scan technique and equivalent sonication (applied electrical power of 80W) and imaging parameters.

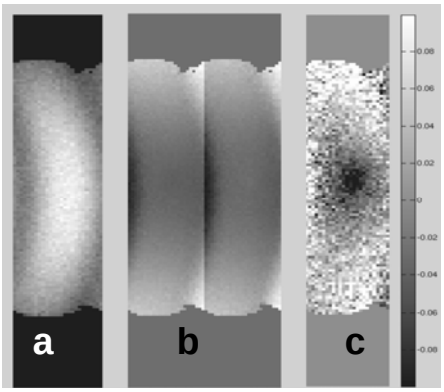

Figure 2. a. Magnitude; **b**. Phase from positive and negative polarity acquisitions; **c**. displacement map (radians) demonstrating the focal spot.

Discussion

The results of this study show that the focal spot can be localized with only two shots with reduced FOV EPI MR-ARFI. This provides a much reduced scan time over the line scan method and, more importantly, requires only two ultrasound pulses of < 20 ms each. The pulse sequence developed for this study may be further improved by reducing the minimum echo time using ramp sampling. The geometric distortions (seen in Fig.2 images), that single-shot EPI is traditionally limited by, could be minimized by reducing the echo spacing time and using high order shimming in the region of interest.

References:

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