Focal Spot Visualization in MRgFUS of the Breast: MR-ARFI vs. T1-weighted FSE

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Introduction

MRI guided focused ultrasound (MRgFUS) as a non-invasive breast cancer treatment has recently shown promising results in clinical trials [1,2,3]. Currently, during the planning stage of MRgFUS in the breast, a low temperature test spot is created to verify the actual location of the focal spot in relation to the planned position [1,2]. The test spots are visualized using proton resonance frequency (PRF) thermometry. However, in some cases the test spots are not visible due to the unreliable performance of PRF in fatty inhomogeneous tissue [1,2]. Two alternative approaches have been proposed for focal spot localization during breast MRgFUS treatments. One method relies on T1-weighted imaging of the test spots with fast spin echo (FSE) sequence [4], and the second approach proposes to image displacement in the focal spot using MR-guided acoustic radiation force imaging (MR-ARFI) [5, 6, 7]. The goal of this study was to test both methods in *ex vivo* breast tissue and to evaluate the potential of both as a targeting tool during MRgFUS treatments in highly adipose breast tissue.

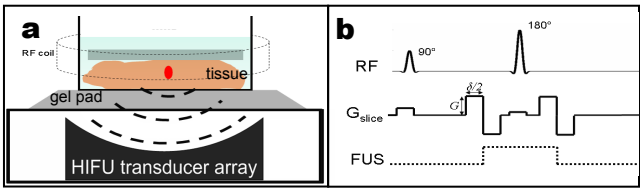

Figure 1. a) Experimental setup; b) Simplified MR-ARFI pulse sequence, showing RF pulses, slice select and encoding gradients on G_{slice}. FUS pulse is emitted during the 2nd and 3rd encoding gradients.

Methods

An *ex vivo* human breast tissue sample, kept at room temperature, was imaged on a 3T GE MRI scanner equipped with an InSightec ExAblate 2000 HIFU system (1MHz) . The experimental setup is shown in Figure 1a. Baseline MR-ARFI and FSE images were obtained with the ultrasound off. For six unique locations of the focal spot, imaging was performed with ultrasound on using first MR-ARFI (acoustic power = 28W, duty cycle = 1.9%, energy 38J), then FSE (acoustic power = 23W, duty cycle = 100%, energy of 460J). The MR-ARFI sequence, shown in Figure 1b, consisted of a 2DFT spin-echo sequence (TE = 41ms, TR = 1s), modified to have displacement encoding gradients applied along the ultrasound beam direction [6]. The duration of each gradient lobe was 6.1ms, and the ultrasound pulse was 19ms long. For T1w imaging, an FSE sequence (TE = 12ms) with ETL = 8 was used. The TR was varied between 200 ms and 700 ms in steps of 100 ms. A different TR value was tested in each focal spot location. Imaging was timed such that the sonication and the scan ended at the same time. Images acquired had a FOV of 22 x 11cm^2, matrix size of 256 x 64, and bandwidth of 15.62kHz.

SNR of the signal in the focal spot was analyzed using MR-ARFI displacement maps and FSE magnitude difference images. Displacement maps were calculated as the difference between two phase images acquired with opposite encoding gradient polarity. The FSE magnitude difference images were calculated by subtracting the images before and during sonication. Mean signal in the focal spot was calculated in a 4x4 pixel ROI prescribed individually for each spot location. The noise was calculated as the standard deviation in a 20x20 pixel ROI placed away from the focal spots in the corresponding baseline images.

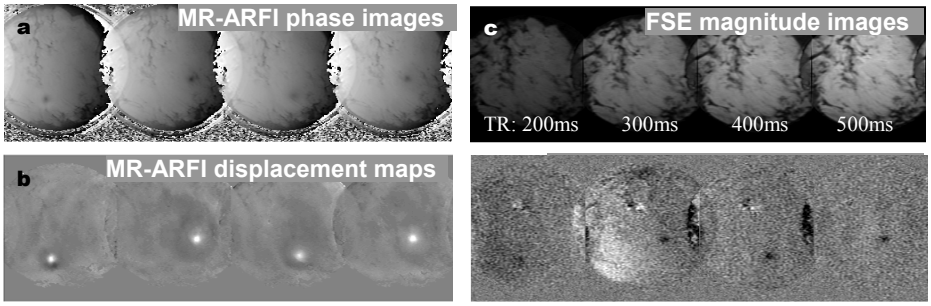

Figure 2. Example images for 4 out of 6 locations: a) phase images obtained with encoding gradients in the opposite direction of the ultrasound beam. b) MR-ARFI displacement maps. c) FSE magnitude images obtained during sonications. d) FSE difference images.

Results

The phase images obtained with one of the encoding gradient polarities, and the displacement maps for each of the focal spot locations, are shown in Figure 2a,b. In both sets of images, the focal spot can be visualized with the naked eye. In the FSE magnitude images obtained during sonications (Fig.2c) the focal spots appear indistinguishable. It is only in the FSE difference images, that the locations of the focal spots become apparent (Fig 2d). SNR analysis of the displacement maps gives SNR of 43 ± 16 for the six different focal spot locations. As for FSE difference images, SNR was found to vary between different TRs (Fig 3) with the highest SNR of 11.5 for TR = 500ms.

Conclusion

The results of this study show that both T1-weighted imaging and MR-ARFI allow visualization of the FUS focal spot. The optimal TR of 500 ms for the FSE method was slightly longer than TR of 400 ms found in rabbit visceral fat at 1.5T [4]. Depositing 10 times less ultrasound energy than during FSE acquisition, the MR-ARFI approach provided much higher SNR at the focal spot. In addition, individual MR-ARFI phase images can be used for immediate feedback, while the magnitude FSE images require either higher ultrasound power, or image subtraction. At body temperature, fatty tissue is expected to have lower stiffness, and that would result in even higher displacement than what was measured in this experiment in the focal spot. Currently this MR-ARFI sequence requires a longer scan time than FSE, but this could be mitigated in the future. In summary, MR-ARFI can provide accurate focal spot localization in inhomogeneous fatty breast tissue and with further calibration the displacement can be potentially linked to the beam quality in the focal spot, which may increase efficiency of treatment targeting.

References:

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