SNR Trade-offs in MR-ARFI of Focused Ultrasound in the Brain

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Introduction

MR guided focused ultrasound (MRgFUS) is of interest in the treatment of various brain pathologies, such as tumors [1] and neuropathic pain [2]. Localization of the ultrasound focal spot is currently achieved with a low temperature rise sonication. An alternative would be to use MR acoustic radiation force imaging (MR-ARFI) [3,4,5] without a temperature rise at all. In one implementation [3] a line scan sequence was used with high b-value unipolar displacement sensitizing gradients. A subsequent modification used bipolar displacement sensitizing gradients and the line scan sequence [4]. The third implementation used a much lower b-value and a 2DFT sequence [5]. Given these differences in the parameters used, the goal of this work was to find the optimum b-value for the displacement sensitizing gradient in MR-ARFI, relevant to in vivo human imaging.

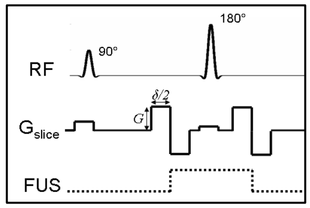

Figure 1. Simplified MR-ARFI pulse sequence, showing the timing of the FUS pulse emission.

b, s/mm²	TE, ms	δ/2, ms	FUS,ms
0.5	22	1.5	9.3
5	29	3.2	12.7
35	41	6.1	18.6
50	44	7	20.1
100	51	8.7	23.8
200	60	11	26.3

Table 1. MRI and FUS time parameters for each tested b-value.

Methods

The MR-ARFI sequence included repeated bipolar displacement encoding gradients in a 2DFT spin-echo sequence. The ultrasound pulse was triggered on during the encoding gradients as shown in Figure 1. The imaging was done on a 3T GE MRI scanner equipped with an InSightec ExAblate 2000 HIFU system. Healthy volunteers (n = 3) and freshly excised ex vivo porcine brain (n = 3) were imaged with our MR-ARFI sequence using bandwidth = 15.62 kHz and TR = 1s. Encoding gradients were applied in slice select direction. The imaging and ultrasound parameters corresponding to the six b-values tested in the study are shown in Table 1. No ultrasound was applied during the human scans, and 8-channel head RF coil was used. In ex vivo experiments, the brain was placed into a gel holder and 0.9% saline solution was used to provide coupling. Ultrasound pulses at 550 kHz and acoustic power of 39W were focused inside the brain tissue during each MR-ARFI acquisition, and an ultrasound-compatible solenoid RF coil was used. Other parameters included FOV of 24cm2 and matrix 256 x 128 for the human subjects and FOV of 16cm2 and matrix of 128 x 128 for the ex vivo tissue.

Displacement maps were obtained from the difference between the phase images acquired with opposite gradient polarity. Noise was estimated from the human brain images as the standard deviation in an ROI placed inside the brain. Displacement values were measured from the ex vivo experiments as the mean value measured in the ROI placed in the center of the focal spot. The displacement-to-noise ratio was weighted by the normalized ultrasound energy for each experiment.

Results

One magnitude and a series of displacement images at different b-values in a human volunteer and the ex vivo brain are shown in Figure 2. The intensity and the size of the focal spot increase with b-value. At the same time, ghosting artifacts also get more pronounced. Figure 3a shows the quantitative data. Quadratic regressions fitting the mean displacement and the noise curves are shown as bold lines. Both normalized SNR obtained directly from the data and SNR calculated from the functions that fit the data are shown in Figure 3b. The latter was used to estimate the optimal duration of the encoding gradient. It was found to be 5.9ms, which corresponds to approximate b-value of 32s/mm2.

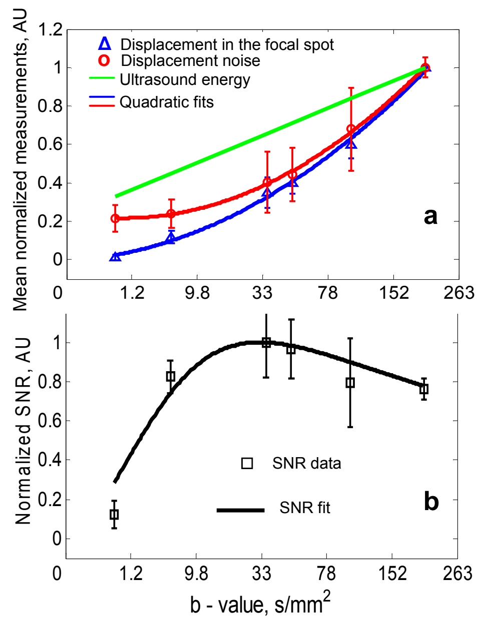

Figure 3. a. Normalized displacement in the focal spot (mean ± std) and its fit, normalized standard deviation of the displacement noise (mean ± std) and its fit, ultrasound energy corresponding to the used power and pulse duration. **b.** Normalized SNR calculated from the data and from the fits to the data.

Conclusion and Discussion

In summary, in this work we studied the SNR tradeoffs of MR-ARFI imaging based on a diffusion-weighted 2DFT spin-echo pulse sequence. The optimal b-value, determined in this study, minimizes the ghosting artifacts due to the brain motion in vivo, and maximizes the displacement in the focal spot, while keeping ultrasound energy minimal.

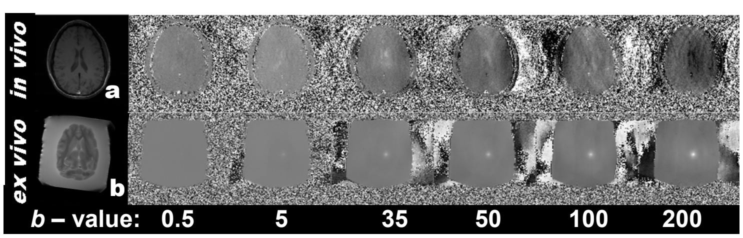

Figure 2. Magnitude image for b=0.5s/mm2 and MR-ARFI displacement images of (a) in vivo human brain (b) ex vivo porcine brain for b-values from 0.5s/mm^2 to 200s/mm^2.

References

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