MR Acoustic Radiation Force Imaging: in vivo Comparison to Ultrasound Motion Tracking

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Introduction

MR acoustic radiation force imaging (MR-ARFI) was developed for measuring displacements induced by focused ultrasound (FUS) pulses (1-4). Compared with conventional MR elastographic approaches using external motion drivers, FUS is able to induce larger displacements at deep tissues. Feasibility studies on phantom and ex vivo tissue samples have demonstrated a near linear relationship between the displacement magnitude and the acoustic power (1-3). However, in calculating the displacement values, simplified models of motion under acoustic radiation force were applied, either assuming sinusoidal motion under the dynamic approach (2,3) or static motion under the quasi-static approach (1). These assumptions depend on the elasticity of the target and have not been validated in vivo. In this work, MR-ARFI was applied in vivo on rabbit thigh muscle and measurements were performed simultaneously with real-time ultrasound tissue motion detection (5), by which time-resolved displacement values during the MR measurement were tracked. Time-averaged results from the two modalities were compared. The purpose was to validate MR-ARFI under the in vivo situation.

Methods

A single-element spherical shell FUS transducer (100 mm diameter, 80 mm focal length) with a central frequency of 1.485 MHz was modulated by rectangular-envelope pulses at 50 Hz (50% on/off duty cycle) to create a local harmonic motion (LHM) at the focal spot. A circular ultrasound imaging transducer (PZT 5, 1-3 piezocomposite, Imasonic, Besançon, France) was mounted inside the central hole of the FUS transducer to track the motion induced by the FUS. The focal volumes of the two transducers were aligned. The imaging transducer had a central frequency of 5 MHz, a diameter of 20 mm and a focal length of 47 mm. Signal tracking was performed using a cross-correlation technique with a 1.5-mm window. The received signal was filtered using a high-pass filter with a cutoff frequency of 4.5 MHz to remove signal contamination from the FUS transducer. The transducers were mounted on a MR-compatible positioning system. More detail of the US motion tracking technique was described in ref 5.

MR-ARFI measured the LHM using a modified 2D gradient-echo sequence with bipolar gradients added for motion encoding. External triggering was used to synchronize MR and ultrasound. To avoid heat accumulation during the MR measurement, three cycles of sonication with 25W acoustical power at 50Hz were applied every three seconds (1% duty cycle). The first two cycles were used as preparation for establishing the motion, and the third cycle was measured by both MR and ultrasound (Fig.1). At 50Hz, motion did not reach a static state at any time point during the cycle. Therefore, to maximize the difference between the bipolar gradients, the positive polar gradient started 5 ms after the FUS sonication, and the negative polar gradient started 10 ms after the stop of the sonication. In this quasi-static approach, MR-ARFI measured the difference of the average displacement under the bipolar gradients (D_{bp}). The corresponding value by ultrasound measurement was calculated for comparison. In ultrasound calculation, 5-degree polynomial fitting was applied to remove occasional spike noise.

In vivo experiments were performed on a 3T MR scanner (GE Healthcare, Milwaukee, WI). The study protocol was approved by our institutional Animal Care Committee. Measurements were performed in rabbit thigh muscles between 15 and 20 mm deep from the skin. A MR image of the *in vivo* experiment setup is shown in Fig.2. The parameters of the MR-ARFI sequence were: TE 28 ms, bipolar gradient amplitude 4G/cm, FOV 12cm, 128x128 matrix, 3mm slice thickness, and effective TR 3s. A baseline image without sonication was acquired for phase subtraction. A 3x3 pixels region of interest (ROI) at the focus was chosen for measurement. The displacement sensitivity was 18.69μm/radian.

Results

The magnitude of tissue displacement varied among locations. One example of ultrasound and MR-ARFI measured results is shown in Fig.3. Ultrasound data shows that the pushing and the relaxation phases of the tissue motion were near exponential. The calculated D_{bp} from the ultrasound data (34.7±4.1 μm) was in close agreement to the MR-ARFI result (30.8±0.8 μm). The scatter plot of nine measurements in Fig.4 shows general agreement between the MR-ARFI measurements and the calculated ultrasound data in our study.

Discussion

Ultrasound result showed that tissue motion under rectangularly-modulated acoustic radiation force is near exponential. Therefore, the model using sinusoid motion in conventional dynamic MR elastography would cause error in estimating the absolute displacement values. In this study we used a quasi-static approach to measure the difference of the average motion between the peak and the bottom, and results were confirmed by the ultrasound data. If dynamic MR-ARFI is of interest, sinusoidal modulation and its optimal frequency should be investigated for a controlled shape of tissue motion in vivo.

References

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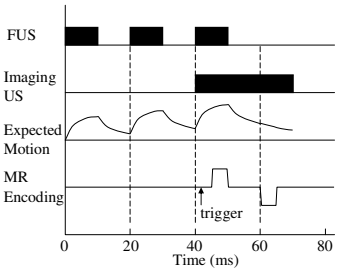

Fig.1 Timing scheme of MR-ARFI and ultrasound motion tracking.

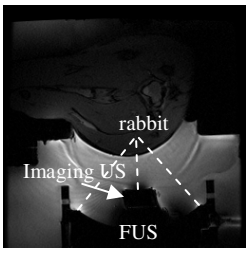

Fig.2 MR image of the *in vivo* experiment setup.

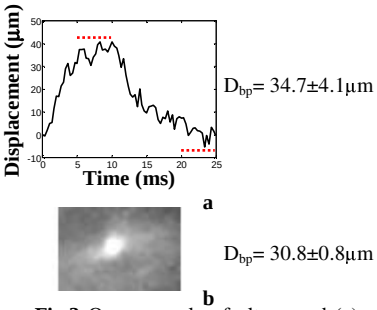

Fig.3 One example of ultrasound (a) and MR-ARFI (b) results. The time periods corresponding to the bipolar gradients are indicated by the dotted lines in (a).

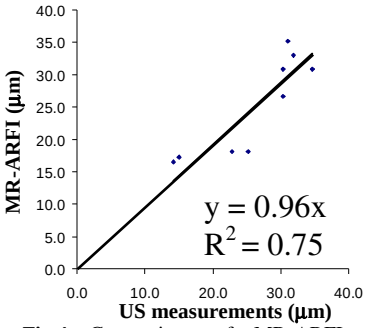

Fig.4 Comparison of MR-ARFI and ultrasound motion tracking measurements.