Temperature and Thermal Dose Analysis Associated with Acoustic Radiation Force from High Intensity Focused Ultrasound in Phantom for Viscoelasticity Measurement

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Introduction: Magnetic resonance acoustic radiation force imaging (MR-ARFI) has been used to either localize the focal spot during high intensity focused ultrasound (HIFU) surgery or measure tissue viscoelasticity from temporally tracking the shear wave propagation initialize by acoustic radiation force (ARF) by an impulse excitation of HIFU. In addition to the mechanical effect of ARF, its thermal effect will potentially result in temperature increase during the MR-ARFI acquisition and may cause tissue damage *in vivo* study due to the repeat application of HIFU pulse. We used the published algorithm simultaneously measure the temperature and displacement to analysis the thermal effect during MR-ARFI acquisition for temporal tracking shear mechanical wave.

Methods: All experiments were performed on a 1.5T commercial MR scanner (Philips Healthcare) equipped with a modified table-top embedded with a 256 channel spherical shell HIFU transducer with five degrees of freedom and an integrated 3-element surface receive coils (Sonalleve, Philips Healthcare).

MRI Data acquisition: A phase contrast based gradient-echo pulse sequence was modified to include motion encoding gradient (MEG) between the excitation pulse and the spatial encoding gradients. The pulse-sequence provided control over the duration, amplitude, timing, and the direction of the application of the MEG (Fig.1). Specific acquisition parameters were: acquired matrix: 256×64; field of view: 200×200mm^2; TR/TE/flip angle = 65ms/13ms/30°; bandwidth: 170 Hz/pixel; scan time: 8.3s . The duration of the symmetric bipolar MEG was 4ms, and the MEG strength was set to 27mT/m. A coronal slice (5mm in thickness) bisecting the plane of the HIFU focus was imaged, and the MEG direction was set perpendicular to the slice-select direction (Fig.2).

HIFU- MRI scanner Interface: The scanner triggers the HIFU device to emit an impulse of 2ms (corresponding to duty cycle of 3%), 250W of ultrasound (1.2 MHz) focusing at 6.7 cm within a tissue mimicking gel phantom. A phase shift (τ) at 0.4ms intervals between the application of the HIFU impulse and MEG was used to capture the transient shear wave propagation (Figure 2).

Data Analysis: 1) A phase difference image from the two sets of raw data (acquired with opposing polarities of MEG was reconstructed for tracking shear wave propagation (Eq.1); 2) A phase addition image from the two sets of raw data and subtracted the background phase shift was reconstructed for tracking phase contributed by temperature (Eq.2); 3) Temperature evolution was reconstructed based on proton resonance frequency method (Eq.3) assuming a 37°C for the initial temperature; 4) The resultant thermal dose was calculated based on Sapareto-Deway equation (Eq.4) at equivalent minutes at 43°C.

$$\Delta\phi_T(n) = \frac{\phi_+(n) + \phi_-(n)}{2} - \phi_0 \quad (1)$$

$$\Delta\phi_M(n) = \frac{\phi_+(n) - \phi_-(n)}{2} \quad (2)$$

$$T(n) = T(n-1) + \frac{\Delta\phi_T(n) - \Delta\phi_T(n-1)}{\gamma\alpha B_0 T_E} \quad (3)$$

$$TD_{43}(t) = \sum_{t=0}^{t=final} R^{(43-\bar{T}(t))}\Delta t \quad (4)$$

where ϕ_T, ϕ_M are the phase contribution from thermal and mechanical effect of ARF, ϕ_+, ϕ_- are the phase map acquired with opposite polarity of MEG. ϕ_0 is the background phase shift. γ is the gyromagnetic ratio, α = -0.01ppm/°C is the PRF change coefficient for aqueous tissue, B_0 is the main magnetic field, T_E is the echo time.

Results: Temperature (Fig. 3) and thermal dose (Fig.4) evolution at the focus of total 48 MR-ARFI acquisitions for tracking shear wave propagation. The temperature increase as the HIFU impulse was applied. The initial slope of temperature increase was ~0.19°C/s, which corresponds to 0.013 °C/s per applied HIFU pulse. As more pulses were applied, the rate of temperature increase begins to slow down due to the heat conduction by medium thermal conductivity. It took around 180s (22nd phase offset for tracking shear wave) to reach 30EM which has been reported to indicator of the onset of tissue alteration.

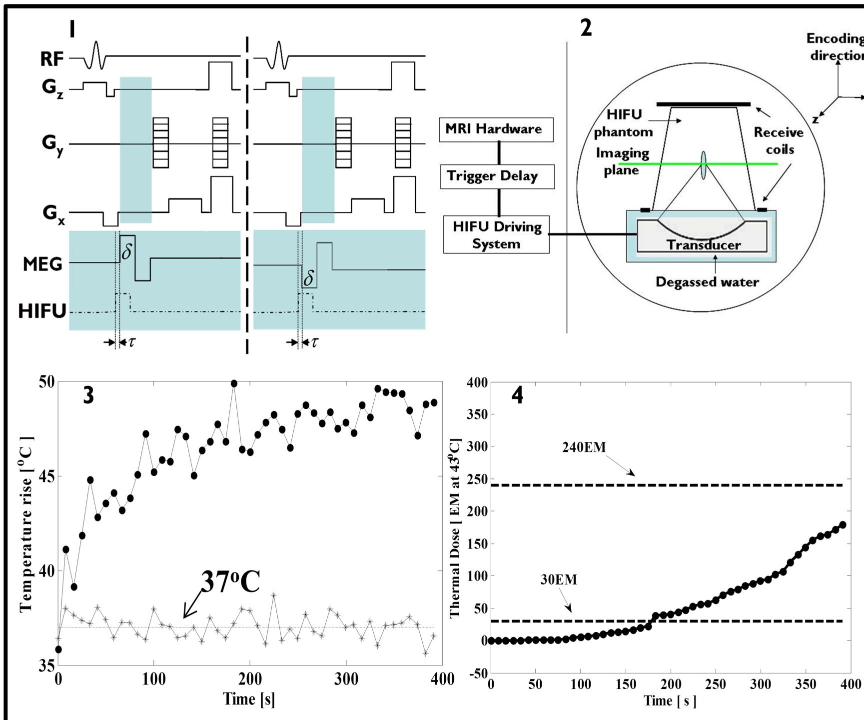

Figure 1: The MRI pulse sequence with MEG is shown on top left; Figure 2: The MR-ARFI system setup; Figure 3: Temperature evolution at focus (dot) and non heating region (star) during MR-ARFI acquisition for tracking shear wave . Figure 4: Resultant thermal dose evolution at focus point (dot).

Discussion and Conclusions: The results from the tissue mimicking gel phantom demonstrate the associated temperature rise and accumulated thermal dose during the acquisition of tracking shear wave propagation. Attention of a safety limit of 30EM should be carefully paid while determining the number of HIFU impulse can be used to generate the mechanical wave in the tissue *in vivo* which may cause tissue damage during MR-ARFI acquisitions.

Acknowledgements: This study was funded by the Ronald MacDonald fund at St. Luke's Episcopal Hospital. It was also partially supported by the Texas Center for Superconductivity at University of Houston and by research support from Philips.

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