Simultaneous measurement of ultrasound-induced thermal and mechanical effects in experimental phantoms using Harmonic Motion Imaging and Thermal Strain Imaging

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Background, Motivation, and Objective

Pulsing regimes can combine heating and acoustic radiation force (ARF) produced by focused ultrasound (FUS) to optimize how ultrasound interacts with neurons in ultrasound neuromodulation. FUS can generate ARF effects and a more confined thermal effect than diffuse tissue heating generated by fast-repeated electrical or light stimulation. Ultrasound and magnetic resonance imaging can assess separately thermal and mechanical effects when FUS ceases. However, assessing the bio-effects during the stimulus can provide better mechanistic understanding, applicability, and efficiency. This study investigates an interleaved ultrasound imaging sequence in phantom that allows the simultaneous evaluation of heating and tissue displacement.

Statement of Contribution/Methods

The plane-wave imaging sequence consisted of a baseline acquisition (P12-5) at a FR_1=14 kHz frame rate, 1 ms before FUS (1.1 MHz transducer). After, the imaging acquisition was interleaved with FUS to monitor the tissue response at a FR_2=1 kHz (Fig.1a). The FUS pulses were amplitude-modulated (AM) at 25 Hz and intensities ranging 0.4-310 $W.cm^{-2}$. The duty cycle (10%, 50%, and 75%) and intensity selection controlled the temperature assessed by thermocouples and simulations based on the Bioheat equation. The tissue displacement was estimated by harmonic motion imaging (HMI) and the temperature rise by thermal strain imaging (TSI) using phase-sensitive cross-correlation processing.

Results/Discussion

The HMI displacements presented a steady-state AM oscillation (up to 70.6 ± 1.5 µm) for low temperatures below 1.8°C (Fig.1b), which corroborate previous findings [1]. Conversely, the thermocouples' temperature evaluation was affected by the viscous heating artifacts (VHA), minimized by an iterative curve fitting [2]. This methodology allowed the TSI calibration, showing TSI less susceptible to motion artifacts than the VHA observed in thermocouple measurements. TSI and thermocouple measurements presented a mean error of ±0.03°C and ±0.24°C, respectively, when comparing temperature estimations in the absence of displacement using thermal simulations. Future studies will explore this methodology for the safety and mechanistic assessment of ultrasound neuromodulation in vivo.

[1] Suomi et al. Phys Med Biol, 61(20):7427-7447, 2016

[2] Kamimura et al., IEEE TUFFC,67(1):70-802020, 2020

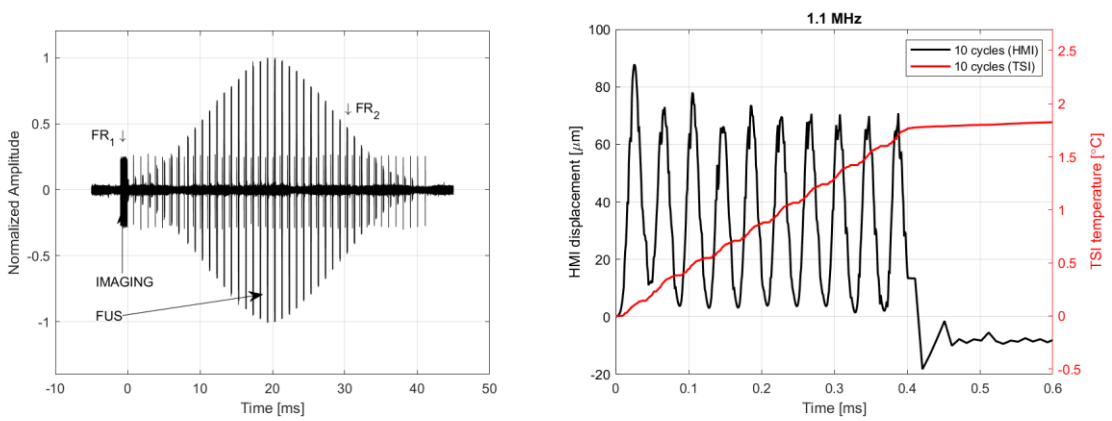

Fig. 1. (a) Plane-wave imaging sequence (IMAGING) interleaved with FUS at 1 kHz frame rate. Baseline images were acquired prior to FUS at FR_1= 14 kHz and interleaved images were acquired at FR_2=1 kHz. (b) HMI displacement was detected for 10 AM cycles with simultaneous assessment of temperature using TSI.