Assessment of the Focused Ultrasound Induced Thermal Lesion Size using Multi-Frequency Single Transducer Harmonic Motion Imaging

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Background, Motivation and Objective

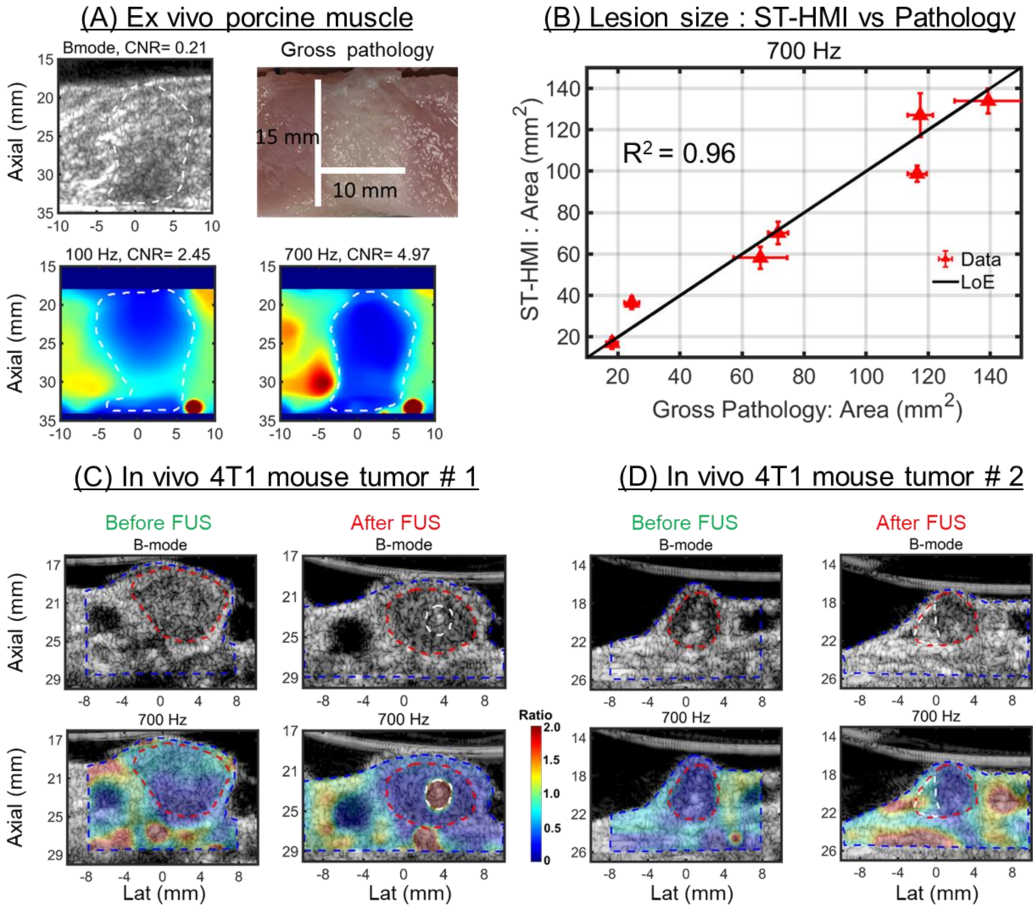
Focused ultrasound (FUS)-induced thermal ablation is gaining popularity for treating tumors due to its low cost and repeatability. In addition to treating the primary tumor, the partial ablation of the primary tumor is shown to have an immunogenic effect on metastatic cancer. While ultrasound imaging is typically used to guide ablation procedures, it suffers to provide an accurate size of the lesion due to low echogenicity changes during ablation. Instead of ultrasound-based morphologic features, an assessment of mechanical properties can better delineate lesion areas because thermal ablation alters the mechanical properties of tissue. Toward the goal of accurately assessing lesion size, this study uses multi-frequency single transducer–harmonic motion imaging (MF-ST-HMI) to generate displacement images of the FUS-induced lesion at an oscillation frequency of 100-1000 Hz in a single acquisition.

Statement of Contribution/Methods

The feasibility of MF-ST-HMI to delineate lesions is performed by FUS-induced ablation of ex vivo chicken (N=3) and porcine (N=4) muscles and in vivo 4T1 (i.e. triple negative) breast cancer mouse tumor (N=2). FUS ablation is performed by a single-element 3.1-MHz FUS transducer with an amplitude modulation frequency of 50 Hz. The peak positive pressure (7.2-12.8 MPa, free field), duration (40-210s), and sonication number (1-3) were varied to create different size lesions. MF-ST-HMI was performed using a Verasonics Vantage ultrasound system and L11-5 linear array imaging transducer with excitation and tracking pulse center frequency of 5 and 9 MHz. Validation of MF-ST-HMI-derived peak-to-peak displacement (P2PD) was performed by comparing with gross pathology. The lesion size was calculated by converting the P2PD/gross pathology image pixel intensity to 0-1 and then by setting the threshold to 0.5.

Results/Discussion

Fig.1 (white, red, and blue contour represent lesion, tumor, and P2PD field of view) shows a gross pathology, B-mode, and representative P2PD images of FUS lesion in porcine muscles (panel A) and mouse tumors (panels C-D). While Bmode was unable to show the true lesion size, the P2PD at 700 Hz provided the highest CNR compared to the other frequencies (panel A). MF-ST-HMI derived lesion size was highly correlated with gross pathology with a root mean square error of 9.5 mm^2 and $R^2 = 0.96$ (panel B). While Bmode only showed increased echogenicity at the lesion location, P2PD show lesions size of 6.4 and 7.2 mm^2 in mouse tumors(Panels C-D). Note, P2PD was lower versus higher in porcine versus tumor lesions. This may be due to the difference in the change in acoustic attenuation of ablated ex vivo porcine/chicken muscles versus in vivo tumors. There was a slight mismatch between before and after FUS ablation planes. This initial feasibility shows that MF-ST-HMI can map different-size FUS-induced lesions by collecting P2PD images at 100-1000 Hz. Future studies will perform automatic registration between before and after FUS planes by collecting 3-D data with histopathological validation of the FUS size of the lesion.



(A) Ex vivo porcine muscle
Bmode, CNR= 0.21
Gross pathology
15 mm
10 mm
100 Hz, CNR= 2.45
700 Hz, CNR= 4.97
Axial (mm)
(B) Lesion size : ST-HMI vs Pathology
700 Hz
R2 = 0.96
Data
LoE
ST-HMI : Area (mm2)
Gross Pathology: Area (mm2)
(C) In vivo 4T1 mouse tumor # 1
(D) In vivo 4T1 mouse tumor # 2
Before FUS
After FUS
B-mode
700 Hz
Ratio
Lat (mm)