Viscoelastic Mechanical Properties of the Canine Liver Before and AfterFocused Ultrasound-Induced Thermal Ablation in vitro

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Introduction: The conventional method of palpation or the elasticity imaging techniques used to detect thermal lesions following thermal ablation techniques in organs and quantify their stiffness may not be effective when the lesions are small or located deep inside the body. Harmonic Motion Imaging for Focused Ultrasound (HMIFU) is a noninvasive and localized method for detection and treatment of small, deep-seated lesions. In this study, we use HMIFU to locally ablate canine liver in vitro. The stiffening of the tissue after thermal ablation is well documented; however, successful application of HMIFU requires quantitative knowledge of the tissue mechanical behavior under various intensities of thermal ablation, which is the aim of this study. Materials and Methods: Canine liver specimens (n=6) were freshly excised immediately after sacrifice and kept immersed in de-ionized and degassed PBS in room temperature during the entire in vitro experimentation. A focused ultrasound system with a 4.755 MHz focused transducer (Riverside Research Inst, NY) was used to induce local thermal lesions in the liver samples. The samples were placed over an acoustic absorber submerged in a de-ionized and degassed PBS bath. Different sets of samples (n=13) were prepared from the untreated as well as ablated livers with an estimated in situ power of 36 W and a sonication time period of 10 s (energy of 360 J) (n=7) (group 1), 25 W and 30 s (750 J) (n=8) (group 2), 30 W and 30 s (900 J) (n=8) (group 3), and 36 W and 30 s (1080 J) (n=8) (group 4).

Raster scanning was performed to generate a conglomerate set of thermal lesions spanning across a region of 1.5×1.5 cm² to 2.5×2.5 cm². After the ablation was completed, the liver specimens were sectioned at the thermal lesion to be tested for mechanical properties using a rheometer (TA Instrument, DE). A biopsy punch was used to extract cylindrical specimens of height h=4.68±0.39 mm and diameter d=5.69±0.37 mm (n=44) from the unablated and ablated liver samples. A precompression of 5% strain was first applied on the samples before oscillatory shear test was performed at 1% strain within a sweeping frequency range of , to measure the complex shear modulus and phase shift. Results and Discussion: Figure 1 shows a representative pathology image of a liver sample containing a thermal lesion. Measurements on the compressive Young's modulus (not shown here) indicated an increase of about 8-9 times in the modulus of groups 1 and 2, and about 5-6 times in that in groups 3 and 4, compared to the unablated specimens. A similar trend was also found in the complex shear modulus of unablated and ablated tissues (Fig. 2.a). Figure 2.b demonstrates an increase in the complex shear viscosity of groups 1-4 ablated tissues compared to the unablated (1st column) tissue, with no significant change amongst the 4 groups. Figures. 2.a and 2.b also show the increase and decrease in modulus and viscosity, respectively, with frequency. The shear loss modulus versus the shear storage modulus for each group is shown in Fig. 2.c, which indicates a reduction in elasticity in the ablated tissues (2nd-5th columns). These results contradicted previously reported findings that increasing the ablation intensity may monotonically induce higher lesion stiffening. Instead, pulverization as a result of thermal ablation may reduce the tissue stiffness. Such changes in tissue mechanical properties should be taken into account in designing relevant systems such as HIFU and RF ablation. Conclusions: This study described, for the first time, the dynamic viscoelastic properties of the canine liver tissue in vitro under focused ultrasound-induced thermal ablation as a result of coagulation or pulverization/cavitation. Acknowledgements: NIH R21EB008512 & RO1EB014496