Pass-through Piston Driver for MR Elastography Assessment of Percutaneous Laser Ablation

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Background: Percutaneous tumor ablation has become an important nonsurgical treatment for primary and secondary malignant hepatic tumors[1]. A critical part of the tumor ablation is intra-treatment monitoring to determine whether an adequate treatment is achieved[2]. A recent study looking at long term efficacy of radiofrequency ablation in treatment of liver tumors over a 6 year period demonstrated that there was a high concordance rate (87%) between the exact sites of local tumor progression and insufficient ablative margin[7]. However, measuring tissue temperature change with MRI remains difficult; it depends on calculated damage and cell death assumptions from the Arrehenius equation. Temperature change is only for a short time, and it is difficult to be sure that the tissue is reliably ablated. It would be desirable to monitor the treatment with a method that can potentially image cellular death. Thermal ablation has been linked to increased stiffness in tissue due to thermally induced random reorganization of denatured proteins. If we could image the change in tissue stiffness, then we could image the actual cellular death and protein denaturation. Our hypothesis is that MR elastography can be used to measure the change in stiffness of the ablation zone during and after the ablation. The purpose of this study is to demonstrate the feasibility of a new acoustic path-thru driver at producing mechanical waves through a laser ablation applicator to the ablation zone.

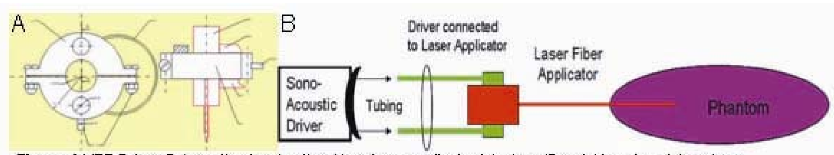


Figure 1 MRE Driver Schematic showing the driver-laser applicator interface (Panel A) and model system arrangement (Panel B).

Figure 2. Laser ablation MRE driver setup. 1: connect to laser source; 2: acoustic piston driver; 3: connect to acoustic source; 4: laser applicator

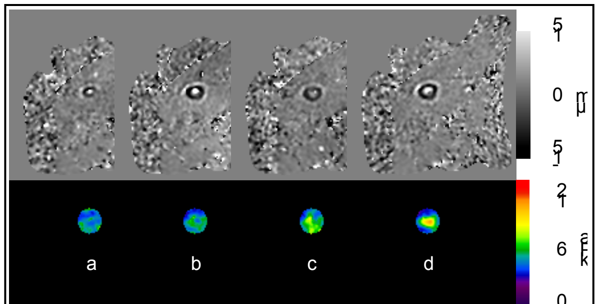
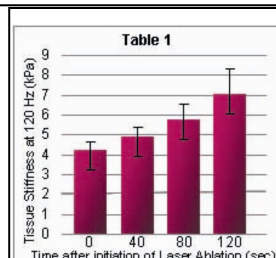


Figure 3. MRE wave images (upper) and elastograms (bottom) of laser ablation lesions in in vivo porcine liver at different time point (sec) after laser ablation: a = 0, b = 40, c = 80, d = 120.

Methods: Testing of the novel path-thru driver is performed first in phantom studies then in porcine liver (Figure1). Phantom studies used agarose gel phantom. All in vivo studies in the porcine liver are performed under the Institutional Animal Care and Use Committee approval, using general anesthesia. Laser Ablation*:* The laser applicator is constructed from optically transparent, flexible, polycarbonate tubing with a diameter of 1.65mm (17Ga, 5F) with a usable length of 11 inches. Introduction is accomplished by using a titanium trochar and 14Ga Teflon catheter as a guide. After placement of the catheter, the trochar is removed and replaced with the laser applicator. The Teflon catheter is then pulled back over the shaft of the applicator prior to laser delivery. For the in vivo studies, the laser applicator is placed in the liver using intermittent MR guidance. During the ablation, MR elastography was performed at 40 second intervals to monitor the changing stiffness. Ablations are performed for 2 minutes. MRE driver: The path-thru driver was made to vibrate the laser applicator (Figure 2). The diameter of the driver is 4 cm, and height is 2.5 cm; it connects to the standard laser applicator and the laser source equipment. The laser fiber tip can go through the driver and allow saline circulation through the laser applicator. MRE sequence: SE-EPI based MRE sequence was developed and performed on 1.5 T scanner (GE, Wisconsin, USA). FOV = 26 cm; phase offsets = 3; MENC = 24 μm/pi-radian; imaging plane: orthogonal to the laser applicator; number of slices = 15; slice position: cover laser ablation lesion; motion sensitizing direction= three orthogonal direction; matrix =256X72; fractional phase FOV=1; NEX=1; Bandwidth =250kHz; TE/TR=1250/55 msec; slice thickness=5mm; scan time= 30 secs, mechanic frequency =120Hz. MRE inversions: 3D phase gradient inversion was implemented on all cases, with 3D directional filter (cutoff frequency 0.1-80 wave/FOV) for calculating MR elastograms [4].



Results: The phantom studies demonstrate that the new sonoacoustic driver can produce mechanical waves along the shaft of the laser applicator with the mechanical waves radiating away from the shaft of the laser applicator. In vivo studies in porcine liver demonstrate that these waves can be produced and measured within the porcine liver in the coronal planes orthogonal to the laser applicator (Figure 3). The stiffness at the tip of the laser applicator can be measured at 40 second intervals during the ablation and demonstrates increasing stiffness over the course of the ablation (Table 1).

Conclusion: This study demonstrates the feasibility of using the path-thru driver to deliver mechanical waves through a polycarbonate laser fiber applicator into the organ tissue which is being ablated and to be able to measure differing tissue stiffness values in the ablation zone during the ablation. This becomes clinically attractive for two important reasons: the elastography images can be acquired during a breathhold with less susceptibility to motion artifact than temperature mapping phase imaging and the stiffness changes are permanent versus the transient changes seen with the temperature.

References: [1]. European Journal of Surgical Oncology 2005;31(4):331-347; [2]. Radiology 2003;228(2):335-345; [3]. Am J Roentgenol 2008;190(6):1544-1551; [4]. Med Image Anal, 2001. 5(4): p. 237-54.