Conformal Bulk Ablation And Therapy Monitoring Using Intracorporeal Image-Treat Ultrasound Arrays

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Abstract. For thermal treatment of soft tissue, an alternative to HIFU is bulk ablation using unfocused or weakly focused intense ultrasound fields. This approach offers faster ablation of large tissue volumes and can be performed in minimally invasive (*e.g.*, laparoscopic or percutaneous) procedures. Here, methods for image-guided ablation of large tissue volumes using compact dual-modality (image and treat) ultrasound arrays are reported including tissue modification caused by the thermal therapy. The dual-modality arrays developed have 16-64 elements spanning apertures of 2-8 mm in elevation and 24-48 mm in azimuth. These devices can provide both therapeutically significant power (*e.g.* source intensity > 80 W/cm^2 at 3.1 MHz) and broad bandwidth (*e.g.* 50% with a center frequency of 3.5 MHz) for imaging. Imaging challenges associated with limited probe dimensions and channel count are met using signal processing techniques that improve definition and contrast, allowing high-quality B-scan images and useful monitoring information to be obtained during therapy planning and treatment. Using linear and rotational scanning methods, large tissue volumes (20-60 cc) can be treated. The approach can be applied for ablation of other soft tissue pathologies, e.g., kidney, heart, uterus, brain, GI tract, etc.

INTRODUCTION

Minimally invasive ultrasound therapy using miniature image-treat arrays has several clinical and technological advantages compared to conventional extracorporeal HIFU approaches [1-3]. In this work an imaging/therapy control system and probes were developed into a soft tissue ablation system and characterized. Preclinical studies included *in vitro* and *in vivo* imaging and therapy of porcine liver, *in vitro* lesioning of bovine liver, imaging quality studies with phantoms, and development and testing of several treatment monitoring techniques [2,3].

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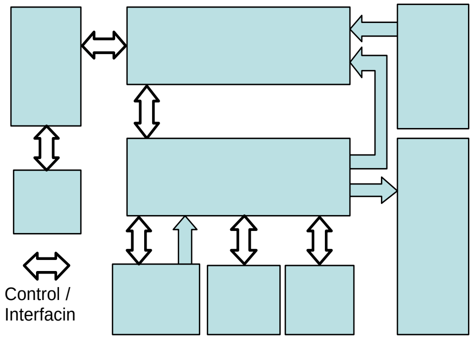

FIGURE 1. Block diagram of system components.

FIGURE 2. Probe, consisting of matching box, cable, probe handle (cover removed) and transducer module. A second module is shown removed from the quick-disconnect handle.

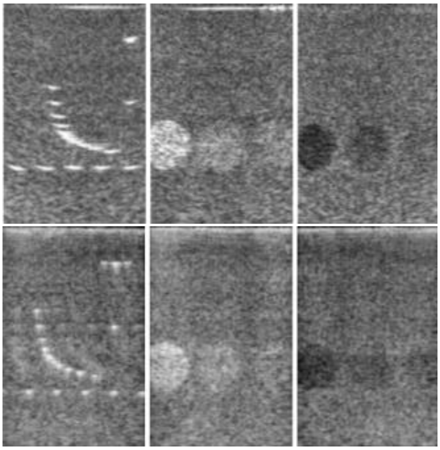

FIGURE 3. Image quality comparison from interstitial image-treat probe (top row), and 3.5 MHz transabdominal probe (bottom row).

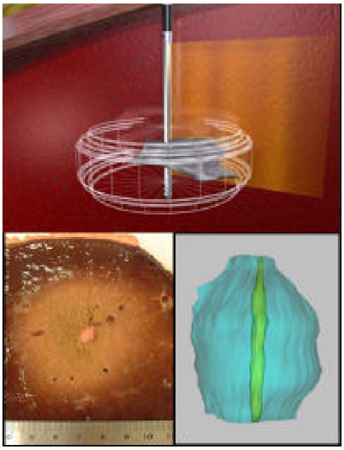

FIGURE 4. *In vitro* porcine liver ablation results via sweeping (pictorial, top). Gross damage tissue slice (left) and 3-D reconstruction of ablation (right).

METHODS

The array based image-treat system is shown in block diagram in Fig. 1. A 64 channel color flow system (Ardent Sound, Mesa AZ) served as the Array Imaging Module (AIM) and accepted conventional imaging probes or interfaced to an Array Therapy Module (ATM) (GTS, Mesa AZ). The ATM is a 64 channel driver and control system that interfaces to imaging/therapy probes or therapy-only probes. This general purpose platform and associated control and treatment software was validated and used with a wide variety of probes in pre-clinical studies. Dual-modality arrays developed had 16-64 elements spanning apertures of 2-8 mm in elevation and 24-48 mm in azimuth. Probes developed for percutaneous liver ablation were based upon a 3mm nominal diameter tube housing a transducer array of 2.2 mm elevation and 50 mm long active length divided into 32 elements. This element count and aperture was a compromise based on the desired field-of-view as well as size and power limits for the electric interconnect. A photograph of a completed probe, with handle, cable and matching box is shown in Fig. 2. Features of the probe and its characterization have been described elsewhere [1,3]. Image quality testing was performed with phantoms and tissue [2,3]. Acoustic and bio-heating simulations were used to optimize treatment plans. *In vitro* and *in vivo* tissue ablation tests were performed on porcine liver and bovine liver [2].

RESULTS

The transducer module had a pulse-echo fractional bandwidth of 50% (matched) centered at 3.4 MHz. Measured acoustic transmit efficiency was 67 % at 95 W, continuous. Imaging performance of an interstitial probe is shown in Fig. 3, and is comparable to or better than an abdominal probe imaging at the interstitial probe depth. A representative scanned ablation using continuous back and forth sweeps over ±180° is shown in Fig. 4. The full aperture was driven at an acoustic power of 74 watts and 80% duty cycle for 31 minutes. Cross sectioned tissue measurements were used to characterize the treatment and reconstruct an ablated volume of 63.9 cm^3, as shown in Fig. 4. The rate of ablation was 2.1 cm^3/min. The continuous depth of ablation and maximum depth were both 24 mm. Continuous ablation depths up to 34 mm have been achieved in similar ablation trials, as well as rates over 3 cm^3/min. Treatment monitoring and image enhancement techniques employed in both *in vivo* and *in vitro* testing further highlight the flexibility and benefits of the minimally invasive therapy/imaging system in the treatment of soft tissue [2,3].

CONCLUSION

Conformal bulk ablation and therapy monitoring using intracorporeal image-treat ultrasound arrays are effective in the visualization, ablation, and treatment monitoring of soft tissues. The approach offers several technological and clinical advantages compared to conventional HIFU. Image-treat arrays and associated system and software have been developed which provide on the order of 100 acoustic watts in a 3 mm diameter package with high transmit efficiency. Image quality is comparable to conventional abdominal probes at depths of 50 mm. Ablation rates of over 2 cm^3/min and depths up to 35 mm (70 mm diameter) have been measured in a large variety of pre-clinical experiments. Using linear and rotational scanning methods, large tissue volumes (20-60 cc) can be treated. The approach can be applied for ablation of other soft tissue pathologies, e.g., kidney, heart, uterus, brain, GI, etc.

REFERENCES

1. Barthe, P.G. and Slayton, M.H., *Proc. IEEE Ultrason. Symp.*, 1249-1252 (1999)
2. Makin, I.R.S., Mast, T.D., Faidi, W., Runk, M., Barthe, P.G., and Slayton, M.H., *Proc. IEEE Ultrason. Symp.,* (2004).
3. Barthe, P.G., Slayton, M.H., Jaeger, P.M., Makin, I.R.S., Gallagher, L.A., Mast, T.D., Runk, M., W. Faidi, *Proc. IEEE Ultrason. Symp.,* (2004).

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