A Laparoscopic HIFU Probe with Integrated Phased Array Ultrasound Imaging

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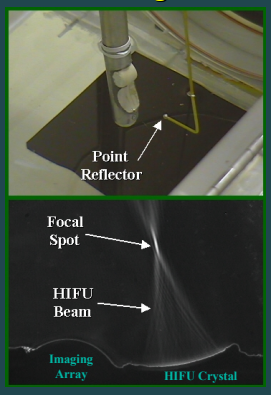
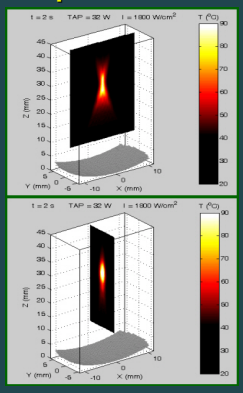
Abstract

Laparoscopic surgery as a minimally-invasive modality is gaining increasing interest among surgeons. We have previously reported on the feasibility of using high intensity focused ultrasound (HIFU) in laparoscopic partial ablation of renal tissue. Here, we report on the design, implementation and characterization of a new hand-held image-guided laparoscopic HIFU probe. The probe consists of a single-element high-power piezoceramic transducer for HIFU energy delivery and an ultrasound convex phased array system for real-time imaging/monitoring of the target region during therapy. The probe body is made to fit in a standard 20-mm surgical trocar. The HIFU transducer has a concave truncated spherical geometry (Focus Surgery, Inc.). The imaging system has a convex phased array transducer (Hitachi Medical Crop., Chiba, Japan) with f_0=6.5 MHz, and DOF=8.0 cm. Schlieren imaging of the HIFU beam was used to evaluate the focusing capability of the HIFU transducer as well as the location of the HIFU focal spot with regard to the imaging screen. Total acoustic power (TAP) measurements showed that the device is capable of delivering TAP values up to 45 W, sufficient to create necrotic lesions in sites up to 4 cm deep in tissue. Computer simulations of the acoustic field coupled with the BHTE temperature response were used to support measurements. The probe prototype was used in an *in vivo* animal study in which necrotic lesions were induced in a lobe of pig's kidney through a laparoscopic procedure. A custom-designed probe holder with integrated positioning system was used for precise movement of the probe tip, to create contiguous lesion volumes. Gross pathology and histology examinations showed the generation of well-delineated and homogenous necrotic lesion volumes in a lobe of the kidney.

Schlieren Registration



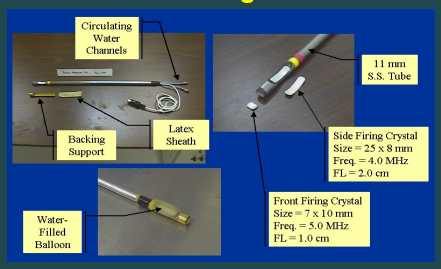
Temperature Simulations

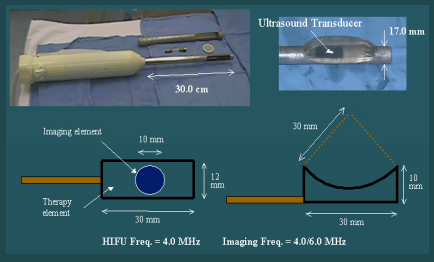


- BHTE Model
- Typical Kidney Tissue Parameters

Previous Designs

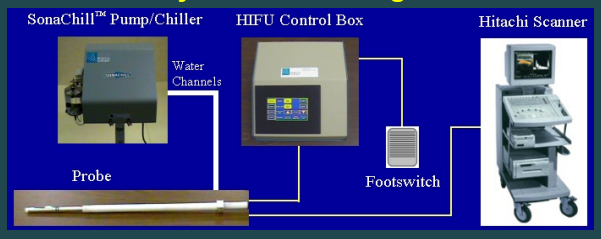
Prototype 1
A simple hand-held probe without ultrasound imaging



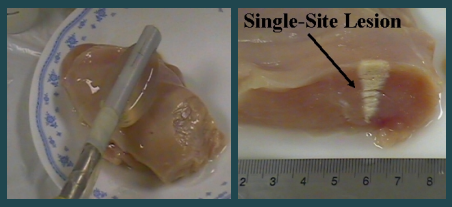


Prototype 2
Controlled by the Sonablate® HIFU system and has real-time bi-plane mechanical scan imaging

System Block Diagram

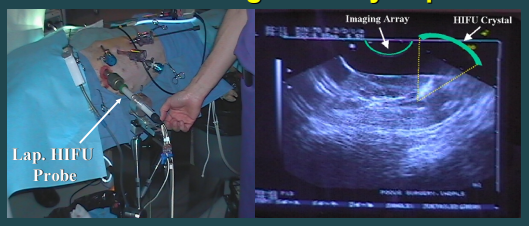


In Vitro Results in Chicken Breast Tissue



- HIFU ON/OFF Times = 2/2 s
- No. of Shots per Site = 5
- TAP = 32 W
- 10mm Water Standoff

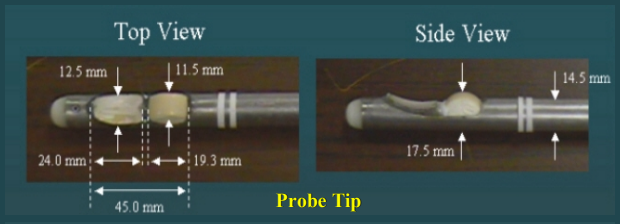
In Vivo Pig's Kidney Experiments

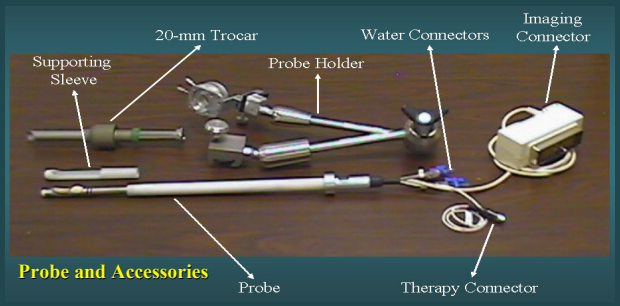


Systematic Appearance of a Hyperechoic Region in the Focal Area

The Hyperechoic Region Gradually Disappears within a few Seconds

Current Design - Laparoscopic HIFU Probe with Integrated Phased Array Imaging





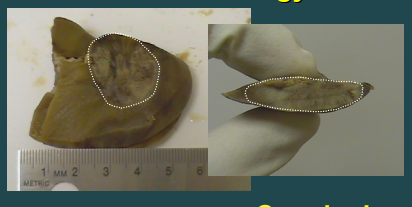
Therapy

- Single-element Truncated Spherical Concave Crystal
- Aperture = 24 x 12.5 mm
- f_0 = 4.0 MHz
- ROC = 30 mm

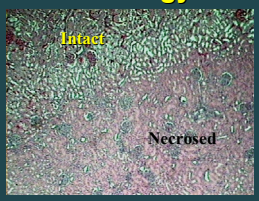
Imaging

- 96-element Hitachi Convex Phased Array (Fingertip)
- f_0 = 6.5 MHz
- DOF = 80 mm
- FOV = 100°

Gross Pathology



Histology



Conclusions

- The probe is hand-held and easy to use for quick and precise tissue ablation through sterile laparoscopic operations.
- It has an integrated real-time phased array ultrasound imaging for treatment guidance and monitoring.
- A custom-designed probe holder with an integrated positioning system was used for precise movement of the probe tip.
- It was used to create repeatable well-delineated contiguous lesion volumes in a lobe of the kidney.
- It can be used to ablate malignant tumors in kidney, liver, and prostate.

Acknowledgements: Thanks to Hitachi Medical Corp., Chiba, Japan, for technical support, and to the New Energy Development Organization (NEDO), MITI, Tokyo, Japan, for funding.