

# COAGULATION OF SWINE LIVER AND CANINE PROSTATE WITH A PROTOTYPE SPLIT-FOCUS TRANSDUCER

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**Abstract** - The split-focus approach has a potential to substantially improve the throughput of coagulation HIFU treatment. A prototype split-focus transducer with two elements at 4.3 MHz combined with a small imaging probe at 6.5 MHz was constructed for transrectal treatment of a prostate. Computer simulation predicted that a coagulation volume approximately three times larger than single-spot focus would be obtained with split focus. Swine liver lobes were intraoperatively insonated for 4 s at a peak intensity of 850 W/cm<sup>2</sup>. A lesion of coagulative necrosis three to six times larger than single-spot focus in volume was formed with the split focus. A canine prostate was then transrectally treated. A cavity, 0.35-0.45 cm<sup>3</sup> in volume, was formed with only four shots of split-focus insonation.

## INTRODUCTION

The split-focus approach was invented about a decade ago for creating a broad heating pattern without forming unwanted secondary foci either in front or behind the focal plane [1-4]. It can reduce the temporal and spatial peak acoustic intensity in ultrasonic hyperthermia by an order of magnitude in comparison with the conventional single-spot scanning approach. Recently, this approach was reported to also have an advantage for ultrasonic coagulation therapy in the higher throughput due to its larger heating patterns. [5,6]

In hyperthermia, the tissue to be treated is heated up to 45°C for a relatively long period of time, typically 10-60 min, an order of magnitude longer than the time needed for the overall temperature distribution in the tissues including surrounding normal tissues to reach the final steady state. In coagulation therapy, on the other hand,

the tissue in the focal spot is heated above the coagulation temperature for a relatively short period of time, typically 1-10 s, with high intensity focused ultrasound, typically in the order of 1 kW/cm<sup>2</sup> [7]. This is much shorter than the time for the overall temperature distribution to reach the final steady state. However, the temperature distribution within a few millimeters from the focus may reach a focal steady state and the tissue temperature at the central acoustic zero of a split focus may rise well above the coagulation temperature even in this short period of time [8].

## PROTOTYPE SPLIT-FOCUS TRANSDUCER

A prototype split-focus transducer with two elements was constructed for transrectal treatment of a prostate (Fig. 1). The dual element PZT transducer (Fuji Ceramics) has a resonant frequency of 4.3 MHz, a spherical curvature radius of 35 mm, and an aperture of 40 mm X 20 mm. The aperture of each element is 40 mm X 10 mm. It is contained in an aluminum housing in combination with a small imaging probe (EUP-

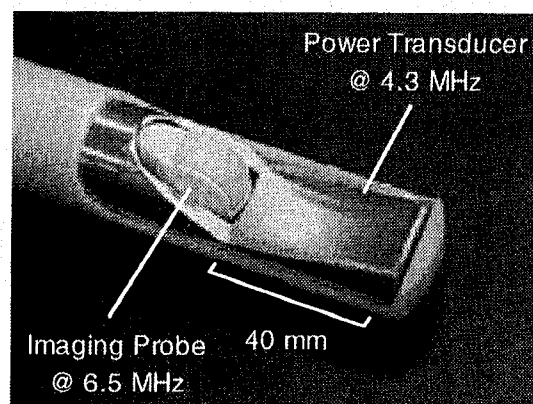


Fig. 1 Prototype split-focus transducer.

F331, Hitachi Medical) at 6.5 MHz having a convex array curvature radius of 10 mm. The whole assembly is contained in a polymer housing 30 mm in outer diameter and covered with a water bag when used in treatment.

The Schlieren profile of acoustic field from the prototype transducer is shown in Fig. 2. With the split focus, the main focal beam was laterally divided into two beams with a separation of about 1 mm, but elongation of the focal zone in the longitudinal direction was minimal.

### COMPUTER SIMULATION OF TEMPERATURE RISE

The temperature rise in tissue during the coagulation treatment using the prototype transducer was computer-simulated. A bio-heat transfer equation was numerically solved using a finite difference method for a three dimensional thermal model with a mesh size of 0.075 mm X 0.075 mm X 0.3 mm with a time step of 0.005 s. The finer lateral mesh size than longitudinal was chosen considering the characteristics of the acoustic intensity distribution. A typical value for tissue heat conductance of 0.55 W/deg/m and that for a blood perfusion rate of 6 kg/m<sup>3</sup>/s were used in simulation.

The maximum peak, the maximum halfway from the transducer to the focus, and the volume of the tissue above the half of the peak temperature rise are plotted in Fig. 3 against the elapsed

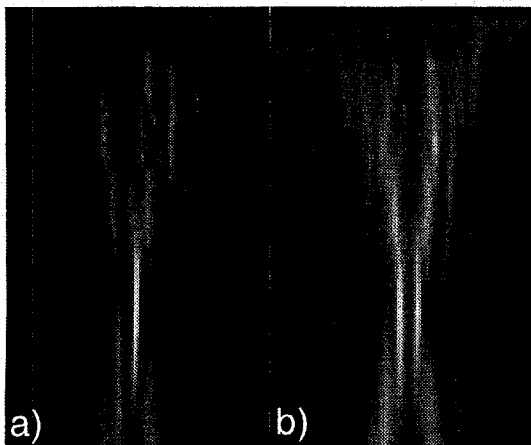


Fig. 2 Schlieren profile of focal field from prototype transducer: a) single-spot focus, b) split focus.

time after the start of insonation. The insonation was continued for 4 s. The acoustic power from the transducer was adjusted so that the maximum peak temperature rise was 50 deg. A volume of tissue approximately three times larger than a single-spot focus was heated above the coagulation temperature with the split focus.

The temperature in the tissue, halfway from the transducer to the focus, decreased approximately in an exponential manner after the insonation was stopped, with a time constant of 83 s. This was almost exactly the same for both split and single-spot focus. It took 38 s longer for the tissue to be cooled down to the same temperature after the insonation with the split focus than that with the single-spot focus.

The tissue temperature rise distribution on the focal plane is plotted in Fig. 4 for 1 s and 4 s after the start of insonation. The ratio in temperature

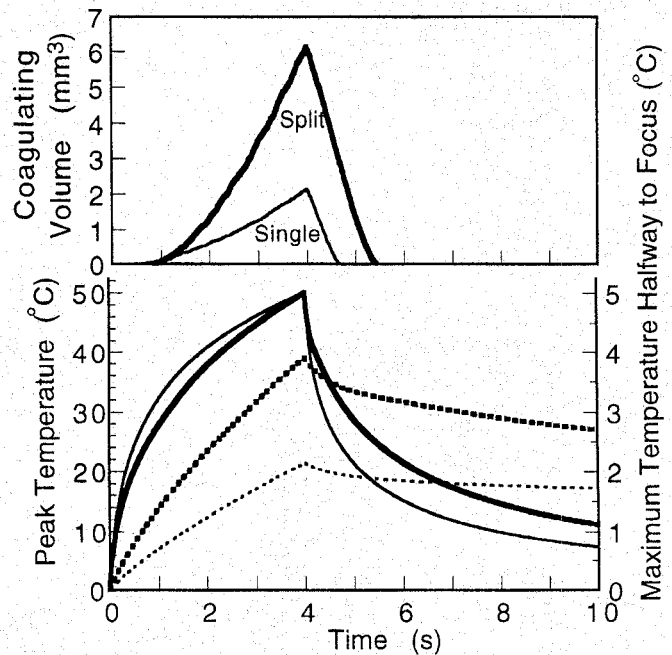


Fig. 3 Tissue temperature rise in coagulation treatment obtained from computer simulation. The maximum peak, the maximum halfway from the transducer to the focus (dotted lines), and the volume of the tissue above the half of the peak temperature rise are plotted against the elapsed time after the start of insonation. The thick and thin lines denote the results for the split and single-spot focus, respectively. Note that the vertical axis is ten times expanded for the dotted lines.

rise between the peak and valley was about 1.5 at 1 s and reduced to about 1.05 at 4 s after the start of split-focus insonation. The temperature at the valley well exceeded the coagulation temperature and a continuous volume for coagulation was formed in tissues within 4 s after the start.

### ANIMAL EXPERIMENTS

Swine liver lobes were intraoperatively insonated with the prototype transducer. After surgical anesthesia liver lobes were mobilized through an upper midline incision. The focus of the power transducer was located in the middle part of a lobe using real-time pulse-echo images obtained with the probe, and the lobe was insonated at a peak intensity in water of 850 W/cm<sup>2</sup> for 4 s. The liver lobes were excised about an hour after insonation, fixed in 10% formalin, and later stained with hematoxylin and eosin (H & E) for histological examination.

Cross sections of the swine liver lobes are shown in Fig. 5. A continuous lesion of coagulative necrosis, with a multiplied lateral size in comparison with single-spot focus, was formed with split-focus insonation. In this particular case, the volume of the lesion was 0.7 cm<sup>3</sup>,

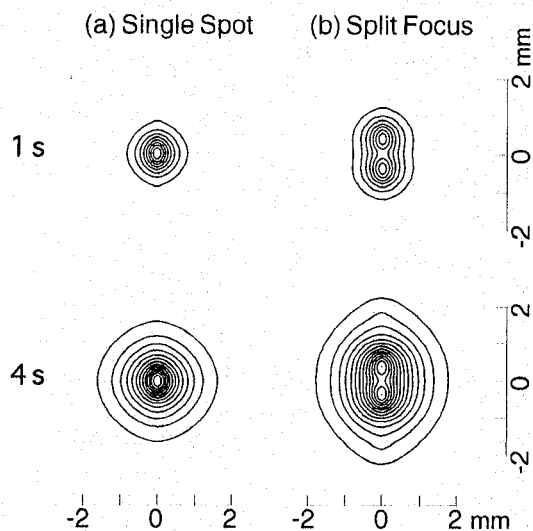


Fig. 4 Temperature rise on focal plane in coagulation treatment. The results from computer simulation are shown for 1 s and 4 s after the start of insonation. Three contour lines are plotted for every ten degrees.

approximately six times larger than that with single-spot focus.

Canine prostates were then transrectally treated with a split focus. After surgical anesthesia, the rectum was cleaned, and the prototype transducer was inserted. The focus of the power transducer was located in the prostatic tissue around the urethra using real-time pulse-echo images obtained with the probe, and the tissue was insonated at a peak intensity in water of 1.7 kW/cm<sup>2</sup> for 4 s. Two weeks after the insonation, the prostate was examined transrectally with an ultrasonic imaging probe at 7.5 MHz. A month later, the dog was sacrificed and the prostate was excised and fixed in 10% formalin.

A cavity of 0.35-0.45 cm<sup>3</sup> was formed around the urethra with only four shots of insonation. This was first observed with transrectal ultrasonic imaging, then confirmed with X-ray by fill-

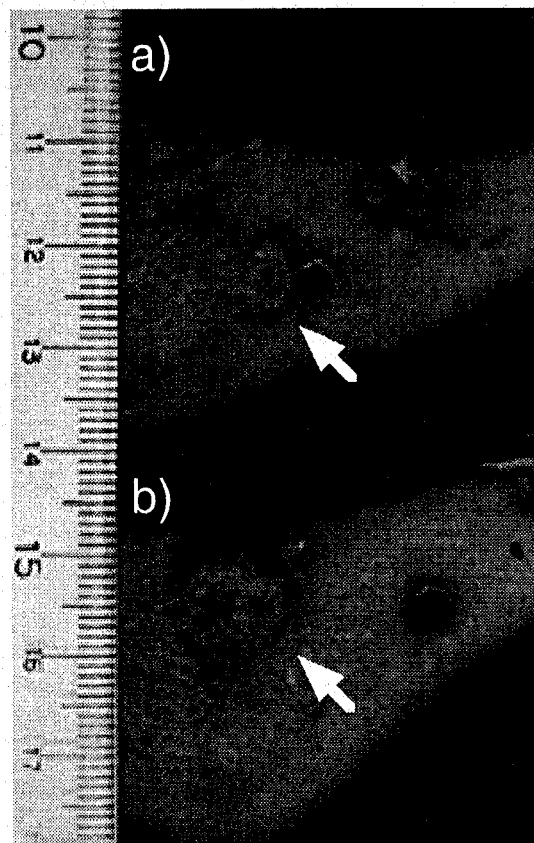


Fig. 5 Cross-section of swine liver after coagulation treatment. The liver lobes were excised about an hour after the insonation at a peak intensity of 850 W/cm<sup>2</sup> for 4 s with a) single-spot and b) split focus.

ing the urethra with a contrast agent, and further confirmed with the excised sample.

#### DISCUSSION AND CONCLUSION

A continuous, laterally enlarged volume of coagulation, three to six times larger than with single-spot focus, was formed with split-focus insonation using the prototype dual element transducer in the animal experiments as well as computer simulation. In computer simulation, the tissue temperature out of the focal zone after insonation was reduced with the same time constant of approximately 80 s with both split and single-spot focus. It took approximately 40 s longer with split than single-spot focus for the tissue to be cooled down to the same temperature. A longer interval between insonation, typically 1.5 times or less, may be required for split than single-spot focus. Therefore, the overall throughput of ultrasonic coagulation treatment will be significantly improved in the split-focus approach. Even higher throughput is expected with a transducer with more number of elements.

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