

Experimental Studies of Using of Split Beam Transducer for Prostate Cancer Therapy in Comparison to Single Beam Transducer

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Abstract - A "split beam" transducer arrangement was adapted for the existing benign prostatic hyperplasia (BPH) high intensity focused ultrasound (HIFU) treatment device, Sonablate – 200™ (manufactured by Focus Surgery Inc., Indianapolis, IN) for the treatment of localized prostate cancer. In the split beam configuration the HIFU beam is divided into several beams to create a larger treatment volume per ultrasound exposure which can reduce the overall treatment time. The objective of current study was to compare the necrosis volume and temperature patterns produced from "single beam" and "split beam" operating configurations. Experiments were performed on different test objects including Mylar strip, plexiglass, turkey breast tissue (*in-vitro*) and *in vivo* dog prostates. The results showed that the split beam configuration created larger lesion volume for the same exposure time while keeping the temperature near the rectal wall at the safe levels. Thus split beam transducer (SBT) configuration should be effective and efficient in clinical application for the prostate cancer treatment.

Introduction

For BPH treatment by HIFU, prostate tissue is ablated surrounding the urethra. However for the treatment of prostate cancer, it is required to treat the whole prostate and eradicate all the cancerous cells and surrounding tissue. Using the single beam, this procedure takes very long treatment time. Hence there is a need to improve the treatment time efficiency while maintaining efficacy and safety. Many investigators have suggested use of multi-element array transducer system with very sophisticated electronics timing to drive these arrays [2,3,4,5]. However, this approach is still limited by the fact that the near field heating requires fairly good time delays

between consecutive ultrasound irradiation. Thus a new approach that is not so costly as well as one provides an improvement over the present single beam treatment has been investigated and reported. We have approached this problem by splitting the main ultrasound beam into one main beam that is surrounded by four side lobes of somewhat lower amplitudes. This produces total focal area about three times larger compared to that of a single higher amplitude beam. In addition, tissue heat conduction connects the lesions created by all the beams resulting in a larger necrotic volume per ultrasonic irradiation.

It also results in an efficient method of treatment since it will not have a single high intense beam that could result in vapor formation at the focal site. We coined this HIFU configuration as "Split Beam Transducer" (SBT). By some changes of treatment and imaging transducer circuits and their arrangements the main beam is reduced in its amplitude and is surrounded by four significant side lobes.

To test our hypothesis, computer simulations were performed to demonstrate the effects and differences between these two configurations. The acoustic properties, beam patterns and power output were verified by the standard production procedures at FSI. *In vitro* tests in turkey breast tissue and *in vivo* experiments in dog prostate were carried out and the lesion volumes created by SBT were examined.

The results show that the split beam creates larger volume of lesion than the single beam in turkey breast tissue and also dog prostate. For the single beam used in BPH treatment step size between HIFU lesions was set at 1.8 mm to create connected necrosis. In the current study a step size

of 2.8 mm was used to create connected lesion in turkey breast tissue and in dog prostate. The treatment time was reduced by more than 30% for the same volume of tissue treatment. The results show that the split beam creates larger volume of lesion than the single beam in turkey breast tissue and also dog prostate. For the single beam used in BPH treatment step size between HIFU lesions was set at 1.8 mm to create connected necrosis. In the current study a step size of 2.8 mm was used to create connected lesion in turkey breast tissue and in dog prostate. The treatment time was reduced by more than 30% for the same volume of targeted tissue.

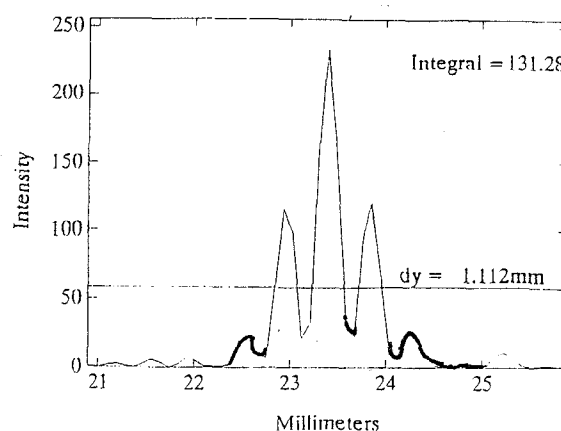
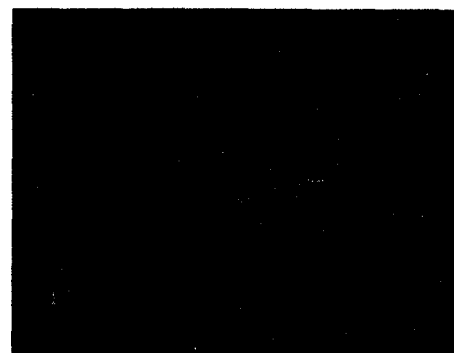
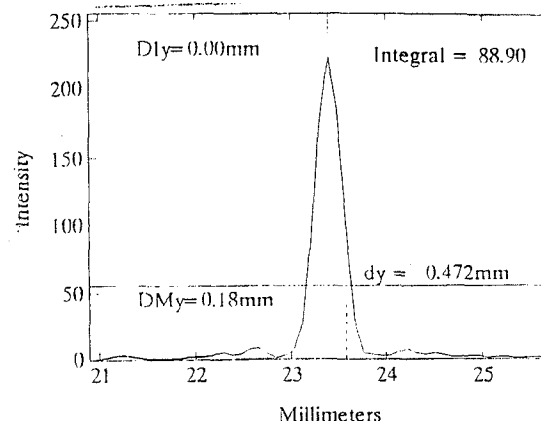
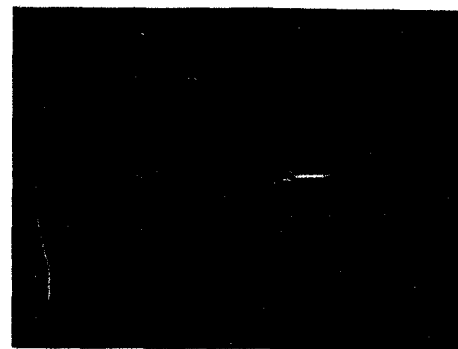
Methods and Materials

The details of the Sonablate – 200™ system are already described earlier [1]. Briefly, the spherically focused transducer of the Sonablate – 200™ HIFU device contains dual elements on the same PZT crystal. The center element serves both for imaging and therapy while the outer element serves for therapeutic purpose only. If the center element is fully incorporated in therapy mode the beam produced is sharp which we termed it as “single beam”. If the center element is not used during the therapy then the acoustic beam is diffracted, with a reduced amplitude main lobe with four side lobes.

Beam Characterization: Both beam patterns are pictured with Schlieren imaging system and shown in Figure 1 with the beam profiles in transverse and longitudinal planes for the single and SBT transducers.

Computer Simulations: The beams were also computed using numerical integral method with small grid size. The following parameters were used during the simulation run: Frequency = 4 MHz, Focal length = 3.5 cm, Transducer aperture = 30 mm x 22 mm. Inner element diameter = 10 mm. Figure 2 a and b shows the simulation results for SBT and the single beam configurations in the focal field.

Figure 1. On the right shows the beam patterns in the transverse planes for a single and split beam transducer configurations. The same transducer configurations were tested on Schlieren system.



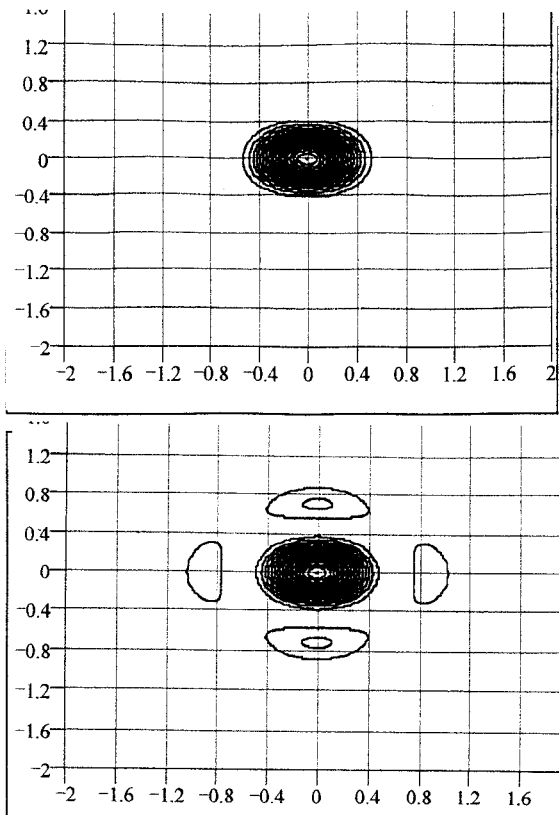


Figure 2. Computer simulations of a single (Top) and Split beam (Bottom) HIFU transducer in the focal plane.

Mylar and Lucite block Testing: The transducer in both configurations were also tested by using Mylar strips placed at the focal plane and the lesion created on the surface are shown in Figure 3. The areas (spacing equal to 2.8mm) between consecutive ultrasonic treatments are filled up with lesion by SBT while there are significant gaps between the lesions when the single beam is used at the same power level of 30Watts.

In-vitro Testing: Fresh turkey breast tissue was used for *in vitro* experiments. The tissue was immersed in a water bath maintained at 37°C temperature. Thermocouples of 0.002-inch diameter (Physitemp, New Jersey) were introduced into tissue by a thin needle to monitor the temperature at the entrance of ultrasound beam and close to the focal point. At the end of ultrasound exposures the tissue were sliced and the lesion size and shapes were measured. The individual lesions by SBT were significantly larger in size.

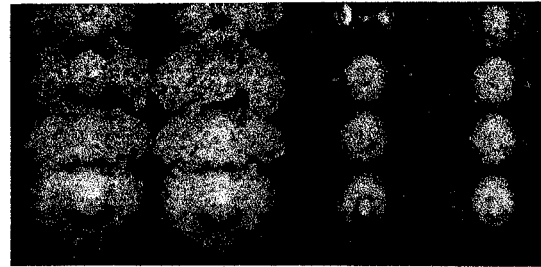


Figure 3. Lesions created in a Mylar strip at 2.5 mm step size. Lesions on the left were created using the SBT and on the right with a single beam HIFU transducer using the same TAP value.

In-vivo testing: In order to verify the efficacy and safety of SBT HIFU under the influence of blood perfusion *in vivo* animal study was conducted on male dogs by using the Sonablate – 200TM. Ultrasound probe was inserted from rectal position as similar to the clinical procedures after the animals were anesthetized. The thermocouples were placed under the real-time ultrasound guidance and temperatures were recorded using a sixteen-channel thermometry system (LT-100, Labthermics Inc., Champaign, IL). The positions of these thermocouples are schematically shown in Figure 4. After the treatment was completed the animals were sacrificed and the prostates, bladders and rectal were preserved in formalin solution for histology examinations.

Results and Discussions

At the same total acoustic power (TAP=35Watts, focal length = 4.0cm) tissue necrosis from SBT is wider than single beam and the focal depths are very similar. The lesion width for SBT at focus estimated is greater than 3 mm. Fig. 4 shows the temperature measured by the thermocouples.

Figure 5 shows the lesion created on male dog prostate gland. At 2.8 mm spacing between consecutive sectors the treatment time was reduced from 1hr to 35minutes and the treated prostate tissue volume was necrotic without any rectal injury. This demonstrates possible improved performance and safety of SBT in prostate cancer treatment as compared to a single beam treatment.

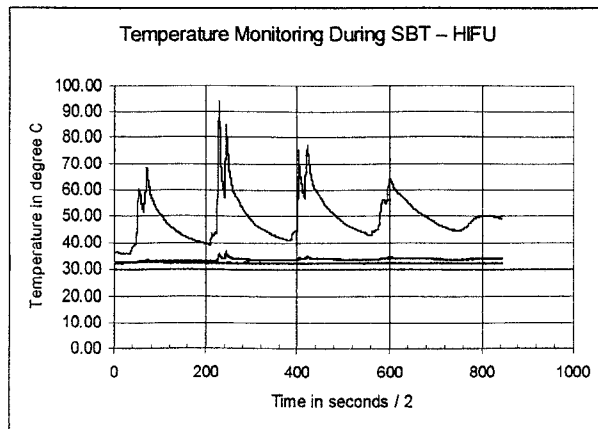


Figure 4. Temperature monitoring of Split Beam HIFU at various locations in the dog prostate treatment. The thermocouples were placed at the rectal wall, near the treatment zone and the prostate capsule and in the body. The peak temperature was recorded when the HIFU beam intersected the TC. The transducer moves 3 mm both longitudinally and laterally for subsequent exposure.



Figure 5. Canine's prostate treated with the SBT HIFU. The inner core shows the contiguous necrotic tissue

Acknowledgement: This work was supported in part by Focus Surgery Inc. and PHS Grant Number 1 R43 CA81340, awarded by the National Cancer Institute DHHS and New Energy Development organization of MITI, Japan.

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