An A-Mode Ultrasound Technique for Tracking the Advance of Coagulation Front in Laser Irradiated Tissue

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INTRODUCTION

Thermal therapies using laser, microwaves, radio frequency irradiation and high-intensity focused ultrasound have shown great promise and potential for minimally invasive treatment of benign and malignant lesions. To effectively treat lesions without damaging the surrounding normal tissue, techniques that could monitor the advancement of thermal damage front in coagulation treatment are highly desirable. To the best of our knowledge, there has been no published work capable of automatically and quantitatively determining the advance of coagulation damage front in heated tissue. The aim of this communication is to present a non-invasive A-mode ultrasound technique that we developed in attempt to fill this knowledge gap.

PRINCIPLE OF THE TECHNIQUE

The physical basis of our technique is that when coagulation is taking place in a tissue region, owing to tissue biological structure change, the waveform of echo signal scattered from that region should be changing accordingly. Our technique consists of three major steps. In the first step, we track RF echo signals scattered from many small tissue regions during heating using a conventional cross-correlation echo tracking technique. In the second step, we compute the correlation coefficient between the currently tracked echo signal and a reference signal that was scattered from the same tissue region and acquired just before the coagulation began. We use this coefficient as a measure of waveform change and relate the waveform change to the coagulation-induced tissue structure change via an automatic procedure. To test our technique, we carried out in-vitro experiments in which fresh dog liver samples were irradiated using Nd:YAG laser. Good agreement was found between ultrasonically determined and visually inspected coagulation depths.
EXPERIMENTS AND RESULTS

The experimental setup is depicted in Fig. 1. Fresh dog liver sample was immersed in pure or saline water at room temperature (23 °C) in a water tank, and placed on a Plexiglas plate, over a 3cm-diameter circular hole in the center. Nd:YAG (1064nm wavelength) laser radiation delivered via a 600μ-diameter optical fiber was used to heat the tissue. The laser beam spot diameter on tissue surface was adjusted to 5mm, and the distance between the tissue top surface and water surface was maintained at 15 mm in all the experiments to ensure the same amount of optic attenuation in water. A 13mm-diameter 10 MHz broadband single-element focused ultrasound transducer was used. Before heating, the initial speed of sound in tissue was measured using a conventional time of flight technique. The speed of sound information was used to determine from which part of the tissue an echo signal was scattered. Fig. 4 shows the progress of coagulation front determined from Fig. 2. Table 1 lists the conditions and results of 10 experiments. For these experiments, the mean coagulation depth, as determined by visual inspection, was 6.2 mm, whereas the root mean square difference between ultrasonically and visually determined coagulation depths was 0.7 mm. The good agreement between visually inspected and ultrasonically determined coagulation depths shows the potential of our technique for automatically determining coagulation front in thermal therapy.

FIGURE 1. Experimental setup.

FIGURE 2. Temporal and spatial variations of β during heating. The results are computed based on the echo signals acquired in experiment #6. The position at distance = 0 corresponds to the tissue surface facing the laser.

FIGURE 3. The position of coagulation front is indicated by z_{peak}. The values of β were computed at 90 seconds into the heating, and based on the echo signals acquired in experiment #6. The position z = 0 corresponds to the tissue surface facing the transducer.

FIGURE 4. The progress of coagulation front during heating as determined by our ultrasound technique in experiment #6.

<table>
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<tr>
<th>Experiment #</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<th>7</th>
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<td>15.7</td>
<td>15.7</td>
<td>20.9</td>
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<td>355</td>
<td>40</td>
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<td>125</td>
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<td>100</td>
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<td>Coagulation depth (visual) (mm)</td>
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<td>5</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>7</td>
<td>7.5</td>
<td>10</td>
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<td>Coagulation depth (ultrasound) (mm)</td>
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<td>5.5</td>
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<td>7.7</td>
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<td>10.6</td>
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ACKNOWLEDGMENTS

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