2P5-2

Proceedings of Symposium on Ultrasonic Electronics, Vol. 35 (2014) pp. 307-308
3-5 December, 2014

Analysis of Decorrelation in Ultrasonic Echo Signals Coincided with Tissue Change due to High-Intensity Focused Ultrasound Enhanced by Cavitation

キャビテーション援用超音波加熱におけるエコー信号の非相関と組織変化の解析

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1. Introduction

High-intensity focused ultrasound (HIFU) is a noninvasive technique for thermal ablation of solid tumors. Ultrasound beam can be focused to a target tumor such as cancer to be thermally coagulated. A noninvasive technique to monitor thermal lesion formation is necessary for enhance the accuracy and safety of HIFU treatment.

In this study, ultrasonic RF signals during HIFU exposure were acquired to use for ultrasonic imaging. In the presence of cavitation mirobubbles generated by HIFU in the focal region, the cross-correlation between image frames was calculated and used to estimate the coagulated region as well as the cavitation region. Pathological examination of the coagulated tissue was also performed for comparison.

2. Material and Methods

2.1 HIFU exposure and data acquisition

A freshly excised chicken breast tissue was perfused with degassed saline to eliminate remaining gas and dissected to samples, and a sample was set in a tank containing degassed water. HIFU at 1.2 MHz was generated from a focused transducer (Imasonic) with both focal length and diameter of 100 mm. An ultrasonic probe (UST-5412, Hitachi Aloka) with a center frequency at 7.5 MHz was set with its axis perpendicular to that of HIFU.

The sequence of HIFU exposure and RF data acquisition is shown in **Fig. 1**. The HIFU sequence consisted of two kinds of exposure. First, trigger pulses at an intensity of 30 kW/cm^2 with a total duration of 100 μs were irradiated. It was immediately followed by heating waves at an intensity of 2.0 kW/cm^2 with a total duration of 45 ms. This cycle was repeated 200 times, resulting in a total duration of 10 s.

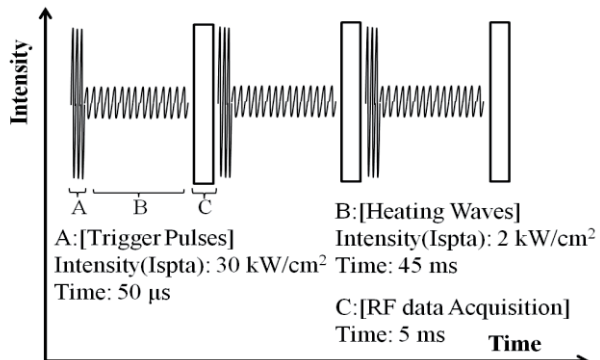

Fig. 1 Sequence of HIFU exposure and RF data acquisition.

2.2 Data analysis

To estimate both regions of coagulation and cavitation, cross-correlation was calculated between image blocks in adjacent frames. Matching between the blocks was evaluated by a cross-correlation coefficient, calculated as

$$R = \frac{\left| \sum_{i=1}^{M} \sum_{j=1}^{N} T(i,j) I^{*}(i,j) \right|}{\sqrt{\sum_{i=1}^{M} \sum_{j=1}^{N} |T(i,j)|^2} \sqrt{\sum_{i=1}^{M} \sum_{j=1}^{N} |I(i,j)|^2}} \quad (1)$$

Plotting the maximum value of the correlation coefficient as a function of the reference block position, a motion compensated distribution of correlation between the entire images can be depicted.

2.3 Pathologic examination

After HIFU exposure, samples were observed pathologically. They were frozen by use of liquid nitrogen, cut in 10 μm thick slices, and stained with haematoxylin and eosin (H&E). The regions of coagulation were determined in the low-power microscopic field.

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3. Result and discussion

Minimum hold values of the cross-correlation coefficients between adjacent frames were calculated for HIFU duration up to 10 s and mapped in **Figs. 2(a)** and **(b)**. Decorrelated regions fluctuated probably due to oscillating cavitation bubbles, resulting in a relatively small effect of tissue change on decorrelation between adjacent frames. Low correlation is observed in **Fig. 2(a)** in the central region corresponding to the HIFU focal spot, where RF signals were varied probably by cavitation. **Fig. 2(b)** shows minimum hold values of the cross-correlation coefficients for 10 consecutive pairs of adjacent frames. The main decorrelated region seems to be the region of tissue change and cavitation. However, scattered decorrelated regions also spread outside around the focal spot, which might have been due to the temperature rise around there.

(a) (b)

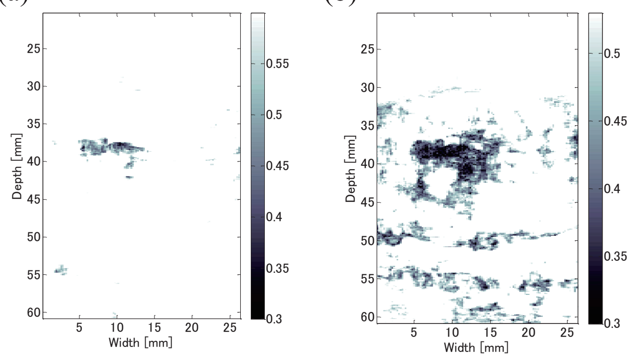

Fig. 3 Distribution of cross-correlation coefficient
(a) between adjacent frames
(b) minimum hold value for 10 consecutive pairs of adjacent frames

Fig. 3 shows the sample of tissue stained with H&E. There is much of atrophy of muscle fibers, seen entirely white. This whitely region is thought to be the actual coagulation region. Its measured axial and lateral size was about 6.6 and 9.5 mm, respectively, and the area was about 54.8 mm^2. In **Fig. 4**, the area of the region with correlation below certain thresholds, seen in **Figs. 2(a)** and **(b)**, is compared with the actual coagulation area seen in **Fig. 3**. The area from **Fig. 2(a)** is much smaller than the actual coagulation area when the cross-correlation coefficient threshold is set at 0.5-0.6. The area from **Fig. 2(b)** roughly matches with the actual coagulation area when the cross-correlation coefficient threshold is set at 0.525, but this optimal threshold varies depending on the sample.

4. Conclusion

In this study, ultrasonic RF signals during HIFU exposure were used to estimate the regions of

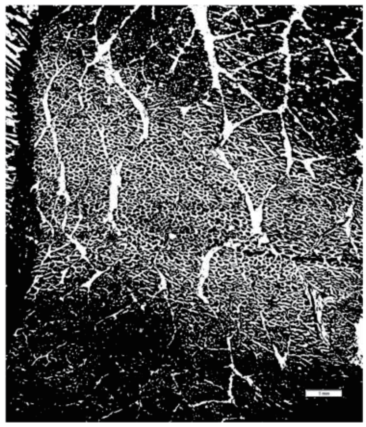

Fig. 3 The sample of tissue stained with H&E.

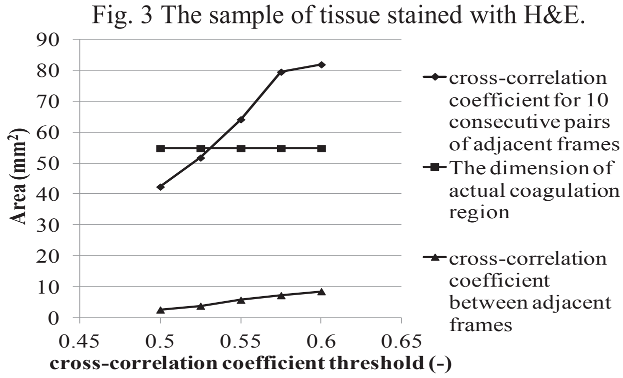

Fig. 4 The dimension of the region low correlation seen in Fig. 2(a), Fig. 2(b) and the actual coagulation region seen in Fig. 3.

coagulation and cavitation by calculating cross-correlation coefficients between frames. The results show decreased correlation between adjacent frames in the HIFU spot, probably corresponding to cavitation region. They also show that the area with low minimum hold value roughly matches the actual coagulation area from pathology when the cross-correlation coefficient threshold is set properly. However, it is difficult to exactly estimate the coagulation region from the cross-correlation map because the optimal threshold varies depending on the sample.

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