

## Monitoring System for Coagulated Area using Optimal Modulation Frequency of Acoustic Radiation Force

最適な変調周波数を用いた音響放射力による加熱凝固領域計測システムの開発

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### 1. INTRODUCTION

High intensity focused ultrasound (HIFU) treatment has been proposed as a minimally invasive treatment method for diverse applications, such as the treatment of cancerous tumors. The high energy acoustic beam can create irreversible thermal damage at the focus of the transducer. The HIFU beam can be confined to the focal region without inducing irreversible thermal damage to the surrounding normal tissue. The coagulation area per one shot of HIFU is small; therefore, it is necessary to develop an accurate monitoring system for the coagulation area.

Magnetic resonance imaging (MRI) is currently used as the standard non-invasive guidance and monitoring method for HIFU, because it can provide quantitative spatial maps of induced temperature increase. Nevertheless, the cost involved in MRI-controlled treatment is expensive; therefore, another monitoring system using ultrasound (US) is researched. US imaging to facilitate HIFU has advantages with respect to portability, low cost and spatiotemporal resolution. US coagulation imaging methods for monitoring and assessment based on various changes of tissue properties have been reported.

Several groups have employed localized motion imaging (LMI)<sup>1)</sup>. In this method, acoustic radiation force is used as a mechanical input to deform tissue at the focus. In a typical experiment with liver tissue, the stiffness of after coagulation was approximately 10 times larger than that before coagulation<sup>2)</sup>. After coagulation, the tissue stiffness changes are detected as changes of tissue deformation. LMI is a radiation-force-based technique that induces vibration at the focal area for the detection of changes in localized stiffness. The acoustic radiation force is modulated by changing the US intensity. However, in these previous studies, contrast detection of the oscillation change was not sufficient.

The LMI oscillation change reflects the average change of the elastic modulus in the vibrating sample volume. The width of the sampling volume is dependent on the wavelength of the shear wave. Therefore, it is expected that a decrease ratio in the amplitude can be controlled by changing the width of the sampling volume attributed to the amplitude modulation (AM) frequency.

In this paper, our purpose is the optimization of the AM frequency to enhance the detection sensitivity for coagulation using LMI.

### 2. METHODS

Experimental setup and conditions for LMI are shown in **Fig. 1**. The target liver tissue was embedded in polyacrylamide gel. An imaging probe placed at the center of the transducer sends and receives back-scattered echo signals from the vibrating tissues at the focal area. The amplitude of the vibrating tissues can be measured by cross correlation between echo signals in consecutive frames. Decrease ratios of the amplitude were measured as a function of the AM frequency. In this experiment, AM frequencies were 67, 168 Hz. HIFU frequency and intensity were 2.2 MHz, 2.0 kW/cm<sup>2</sup>, respectively.

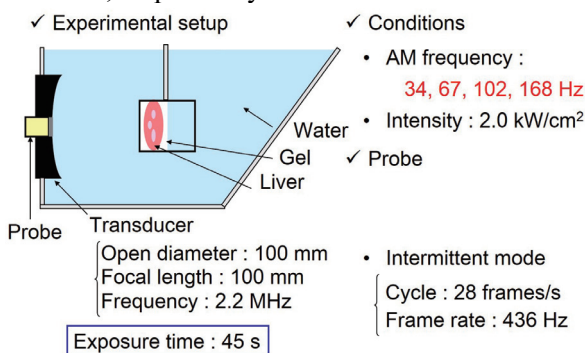


Fig. 1 Experimental setup for LMI and experimental conditions

To evaluate estimated coagulation sizes, we constructed an optical measurement system as shown in Fig. 2. The half of liver tissue as an object was replaced by a transparent polyacrylamide gel. Therefore, a cross section including the HIFU focal plane can be observed with a camera facing the cross section. Obtained image was binarized and each coagulation length in each binarized image frame was estimated.

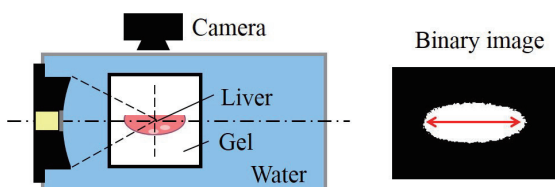


Fig. 2 Experimental setup for optical measurement

### 3. RESULTS

These measured coagulation lengths were compared with results of the optical measurement as shown in Fig. 3 and 4. The black triangle marked line and the red square marked line indicates the result of optical measurement and LMI, respectively. The expansion of coagulated area could be followed by the LMI with low AM frequency (67 Hz) as shown in Fig. 3. In this case of low AM frequency, the sensitivity to detect the beginning of coagulation was not sufficient, due to small average stiffness change in the oscillating area.

On the contrast, the estimated beginning of coagulation by the LMI with high AM frequency (168 Hz) corresponds to the result of optical measurement (Fig. 4). The masked area with gray color showed low signal to noise area due to small oscillation amplitude. In this case, because oscillating area was limited in small area, the expansion of coagulated area could not be followed

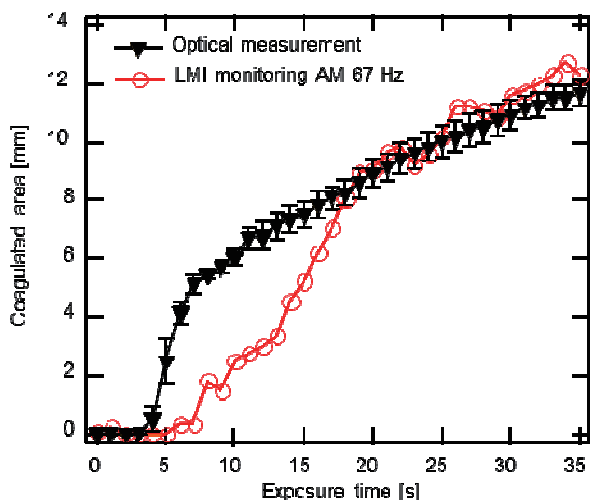


Fig. 3 Comparison between LMI with AM frequency of 67 Hz and optical measurement

by the LMI estimation.

Therefore, combination of low and high AM frequency is considered to be practically useful to correspond to coagulation measurement in the all HIFU exposure period.

However, living tissues have variations by regions or individual differences. Therefore, to validate LMI, it is necessary to conduct a simultaneous measurement of the LMI and the optical measurement using the same tissue sample.

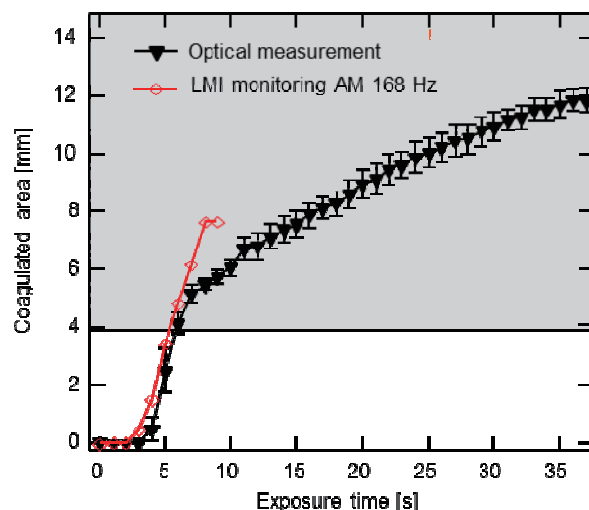


Fig. 4 Comparison between LMI with AM frequency of 168 Hz and optical measurement

### 4. CONCLUSION

We have developed an US monitoring system for thermally induced coagulation using LMI. To enhance the detection sensitivity for a small coagulated area, localized control of the oscillation by changing the modulation frequency was conducted in experiments with excised porcine liver. The results indicate that a low modulation frequency is suitable for the size estimation of large coagulation area due to large oscillation area. On the contrast, a high modulation frequency is suitable for the detection of a small coagulation area or initial coagulation using LMI. In the future, to validate LMI, experiments of simultaneous measurement of the LMI and optical measurement will be conducted using the same tissue sample.

### ACKNOWLEDGEMENT

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