2E2-5

Proceedings of Symposium on Ultrasonic Electronics, Vol. 37 (2016)

16-18 November, 2016

Prediction of ultrasonically induced thermal coagulation from the distribution of absorption of pulsed high-intensity focused ultrasound

強力集束超音波パルスによる超音波吸収分布を用いた
熱凝固領域予測

Ryosuke Iwasaki[1‡], Ryo Takagi[2], Kentaro Tomiyasu[1], Shin Yoshizawa[2], and Shin-ichiro Umemura[1]
([1]Grad. School of Biomed. Eng., Tohoku Univ.; [2]Grad. School of Eng., Tohoku Univ.)
岩﨑 亮祐 [1‡]，高木　亮 [2]，富安 謙太郎 [1]，吉澤　晋 [2]，梅村 晋一郎 [1]
([1] 東北大院 医工, [2] 東北大院 工)

1. Introduction

High-intensity focused ultrasound (HIFU) treatment is a less invasive therapeutic aplication in which ultrasound is generated outside the body and focused at the target tissue to be thermally coagulated. To realize HIFU treatment with safety and reproducibility ensured, visualizing the focal zone is necessary for targeting the therapeutic ultrasound beam because focal spot can be shifted due to the spatial differences in such as the speed of sound and ultrasonic absorption.

The acoustic radiation force, which mainly originates from ultrasonic absorption, induced by HIFU exposure can provide the tissue displacement distribution reflecting the absorption of HIFU even with a short duration, orders of magnitude too short to induce irreversible tissue changes. Therefore, it can be a method to predict the thermal coagulation of the tissue in advance[1)]. In this study, the tissue displacement was dynamically mapped and compared with the actual coagulated region, and the effectiveness of the proposed focal zone visualization technique was evaluated.

2. Materials and Methods

2.1 ARFI imaging

Acoustic radiation force impulse (ARFI) imaging is known as a diagnostic application to assess tissue hardness[2)]. It has the ability to image the strain caused by the acoustic radiation force F, described by the equation (1) below, resulting from focused ultrasound exposure and to estimate the absolute tissue elasticity by measuring the propagation velocity of the shear wave generated by the action of the radiation force remotely.

$$|F| = \frac{2\alpha I}{c}, \qquad (1)$$

where α, I and c are the amplitude attenuation coefficient, the acoustic intensity and the speed of sound, respectively.

The heat Q owing to the ultrasonic absorption is given by the equation (2):

$$Q = 2\alpha_{abs} I , \qquad (2)$$

where α_{abs} is the amplitude absorption coefficient. Since the numerators in the right sides of the equations (1) and (2) match assuming ultrasonic attenuation depends on only the absorption, the distribution of the radiation force is thought to be equivalent to that of the heat source inducing thermal coagulation in the treatment HIFU.

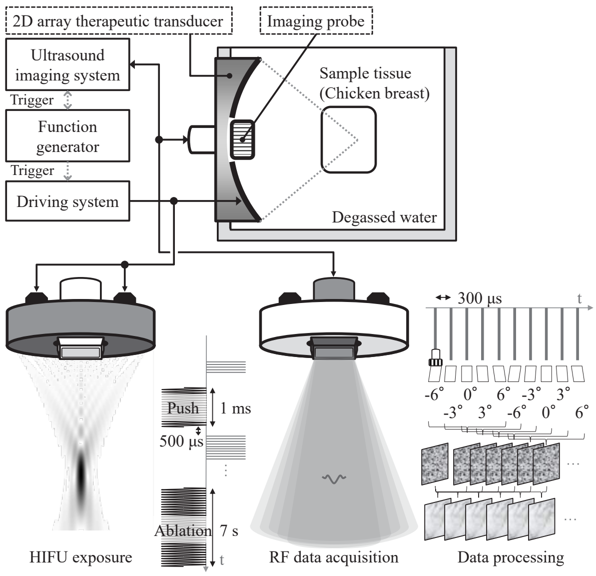

Fig. 1 Schematic of experimental setup and sonication protocol

2.2 Experimental procedure

Experiments were performed in a water tank containing degassed water at 35°C and equipped with a therapeutic transducer as shown in **Fig. 1**. A chicken breast tissue degassed in a saline as a sample tissue was placed in the tank.

The 256-channel 2D-array therapeutic transducer

riwasaki@ecei.tohoku.ac.jp

(Imasonic) with both focal length and diameter of 120 mm was driven by a staircase driving system (Microsonic) at a frequency of 1.0 MHz. To induce displacements inside the sample, HIFU at an intensity of 3.0 kW/cm^2 with a duration of 1 ms was irradiated as a "push pulse". Before and after irradiation, RF data were acquired via a sector probe (Hitachi Aloka Medical UST-52105), set in the central hole of the therapeutic transducer, connected to an ultrasonic imaging system (Verasonics V-1). To avoid interference between HIFU and imaging pulses, an interval of 500 μs was set between push pulse exposure and RF data acquisition. Synchronization between devices made through a function generator. After RF data acquisition for visualizing focal zone, the target sample was coagulated by HIFU exposure at the same intensity as the push pulse with a duration of 7 s and a duty cycle of 90%.

2.3 Data processing

RF data were acquired by transmitting plane wave pulses at a center frequency of 3.75 MHz with steering angles of -6, -3, 0, 3 and 6° with a PRF of 3.33 kHz. The five consecutive data applying delay-and-sum-based receive beamforming were compounded and construct one frame as shown in Fig. 1. This RF frame construction was repeated to track the propagation of displacement after irradiating push pulse. The axial displacements were calculated by using the combined autocorrelation method[3] with a reference frame before the push pulse exposure.

3. Results and Discussion

After the push pulse exposure, the axial displacement propagated as shown in **Fig. 2**. The displacement map at 0 ms was obtained by linear extrapolation using those at 1.1 and 2.0 ms. The displacements at the 4 points (marked with "x" in Fig. 2) at depths of 79, 84, 89 and 94 mm were plotted in **Fig. 3**. The measured values are drawn with solid lines and the linear extrapolation to the end of push pulse exposure is drawn with dotted lines. The extrapolation seems to have succeeded thanks to the high frame rate.

The area with axial displacements exceeding the half maximum in the map at 0 ms in Fig. 2 is shown side by side with the gross pathology of the actual coagulated sample in **Fig. 4**. The distribution of the axial displacement immediately after the HIFU push pulse shows good agreement with the region coagulated by HIFU with much longer duration. This suggests that the displacement map well reflect the HIFU focal zone.

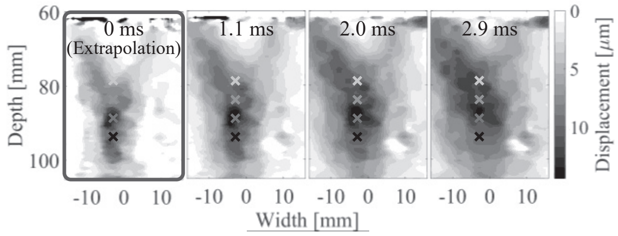

Fig. 2 Shear wave propagation

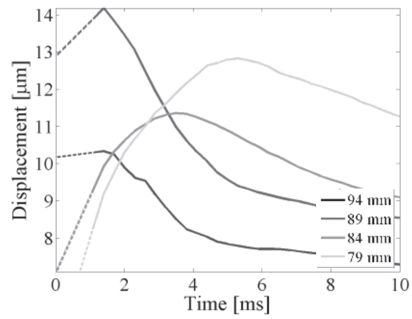

Fig. 3 Time variation of displacements at different 4 depths

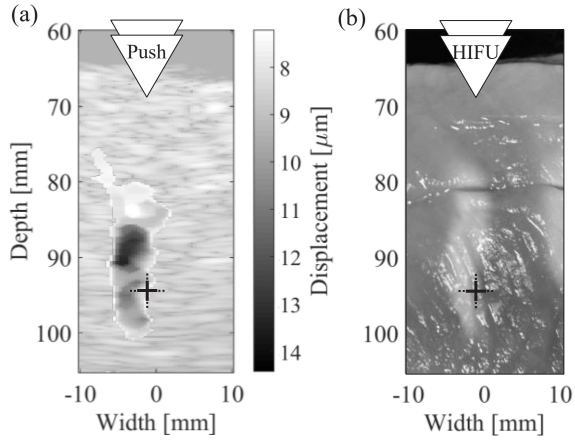

Fig. 4 (a) Displacement map by HIFU-ARFI after extrapolation
(b) Sliced sample after HIFU exposure

4. Conclusion

In this study, a focal zone visualization method employing high-speed ARFI imaging was proposed. The extrapolated displacement immediately after the HIFU push pulse agreed well with the region coagulated by HIFU, which demonstrated potential usefulness of the proposed method to predict thermal coagulation.

References

1. O. Arai, T. Azuma, K. Kawabata, Y. Muragaki and H. Iseki: Jpn. J. Med. Ultrasonics **40** (2013) 495 [in Japanese].
2. K. Nightingale, M. S. Soo, R. Nightingale and G. Trahey: Ultrasound Med. Biol. **28** (2002) 227.
3. T. Shiina, N. Nitta and J. C. Bamber: J. Med. Ultrasonics **29** (2002) 119.