3Pa5-9

Proceedings of Symposium on Ultrasonic Electronics, Vol. 33 (2012) pp. 389-390
13-15 November, 2012

Measurement and simulation of temperature rise distribution in phantom irradiated by weak nonlinear ultrasonic

弱非線形の超音波照射によるファントム内部温度上昇分布の測定と解析

Shin Tanaka[1†], Suguru Sakuma[1], Takenobu Tsuchiya[1], and Nobuyuki Endoh[1]
([1]Kanagawa Univ.)
田中 伸[1†]，佐久間 優[1]，土屋 健伸[1]，遠藤 信行[1] ([1]神奈川大学)

1. Introduction

Acoustics radiation force impulse (ARFI) imaging is possible to quantitatively diagnose at deep tissue in human body. However, ultrasonic irradiation of high intensity and long burst pulse may has a helth risk for human body. One of risk is temperature rise caused by high intensity ultrasonic irradiation[1]. Measurement of temperature rise caused by ARFI irradiation using thermocouple was reported[2]. We have studied about the temperature rise caused by ultrasonic irradiation[3-6]. Sound field was calculated by linear finite difference time domain (FDTD) method. Thermal distribution caused by ultrasonic absorption in phntom was calculated by heat conduction equation (HCE) method from ultrasonic intensity.

In this paper, we develop three-dimensional simulation method using nonlinear-FDTD-HCE method. Comparing simulation result to experimental result of sound field and thermal distribution, it's validity was confirmed.

2. Configuration of experiment and simulation

In order to obtain the sound pressure distribution in media, nonlinear-FDTD calculated the nonlinear wave propagation using the next equations,

$$\frac{1}{c^2}\cdot\frac{\partial^2 p_1}{\partial t^2} = \nabla^2 p_1 + \frac{b}{\rho c^4}\cdot\frac{\partial^3 p_1}{\partial t^3} \ \dots (1)$$

$$\frac{1}{c^2}\cdot\frac{\partial^2 p_2}{\partial t^2} = \nabla^2 p_2 + \frac{b}{\rho c^4}\cdot\frac{\partial^3 p_2}{\partial t^3} + \frac{\beta}{\rho c^4}\cdot\frac{\partial^2 {p_1}^2}{\partial t^2}, \dots (2)$$

where p_1 and p_2 are sound pressure of fundamental and 2nd harmonics wave, ρ and c are density and sound speed in media, t is time, β=1+B/2A is nonlinear coefficient, B/A is nonlinear parameter and b is absorption of sound[7]. Absorption of sound is written by

$$b = \zeta + \frac{4}{3}\eta \approx \frac{2c^3\alpha}{\omega^2}\rho, \dots (3)$$

where η and ζ are shear and bulk viscosity, α and ω are the attenuation coefficient and the angular frequency.

For measurement of sound pressure distribution of transducer, we scan sound field used needle hydrophone in water tank. The center frequency, active diameter and geometric focus length of transducer are 1.1 MHz, 64 mm and 63.2 mm, respectively. Properties of water are ρ=1000 kg/m^3, c =1500 m/s and B/A = 5.0.

For thermal distribution caused by ultrasonic irradiation in media, HCE is given as follows

$$\rho C\frac{\partial T}{\partial t} = \lambda\nabla^2 T + Q \ \dots (4)$$

where T, C, λ and Q are temperature, heat capacity, heat conductivity and heating value, respectively. Heating value is given by

$$Q = 2(\alpha_1 I_1 + \alpha_2 I_2), \dots (5)$$

where

$$I_{1,2} = \left(\frac{1}{t_\mathrm{p}}\int_0^{t_\mathrm{p}} {p_{1,2}}^2\, dt\right)/\rho c, \dots (6)$$

α_1 and α_2 are the attenuation coefficient of fundamental and 2nd harmonics wave, t_P is sound period.

Thermal distribution in soft tissue phantom irradiated by ultrasonic is measured by thermal imaging method[8]. In this paper, we fabricate a split tissue phantom of 90 mm cubic, after IEC 60601-2-37. Properties of phantom are ρ=1000 kg/m^3, c =1500 m/s, α=0.4 dB cm^{-1} MHz^{-1}, C =3750 J kg^{-1} K^{-1}, λ=0.4 W m^{-1} K^{-1} and B/A = 6.0. In irradiated condition in water, pulse repetition frequency (PRF) is 100 Hz, irradiation time is 1 min. and distance from transducer to phantom is 8 mm. After irradiation, thermal image is obtained by thermo camera in air[4].

3. Result of experiment and simulation

Figures 1 (a) and (b) show the comparison of the sound pressure distribution between

----

e-mail : r201170069dt@kanagawa-u.ac.jp

measurement and simulation. Figure 1 (a) shows the sound pressure distribution at central axis. Figure 1 (b) shows the sound pressure distribution at transverse direction at focal point. Focal point is located in 53 mm from transducer as shown in Fig. 1 (a). As a shown in Figs. 1 (a) and (b), simulation results agree well with experimental results near focal point. Figure 2 shows a waveform of experiment and simulation at focal point. Both waveforms of experiment and simulation show nonlinearity as shown in Fig. 2.

Figures 3 (a) and (b) show a comparison of the temperature rise distribution between measurement and simulation. Figure 3 (a) shows the temperature rise distribution at central axis. Figure 3 (b) shows the temperature rise distribution at transverse direction on peak temperature point. As shown in Fig. 3 (a), the point of peak temperature rise is at 53 mm from transducer. The focal length in phantom is the same as focal point in water. Experiment and simulation results agree well as a shown in Figs. 2 (a) and (b).

4. Summary

In this study, we developed three-dimensional nonlinear-FDTD-HCE simulation, and we also measured the distribution of sound pressure and temperature rise. As results of sound pressure and temperature rise, simulation result were good agreements with experiment result. Therefore, we are possible to calculate the distribution of sound pressure and temperature rise in phantom.

Acknowledgment

This study was partly supported by a 2011 Grand-in-Aid for Scientific Research from the Ministry of Education, Culture, Sports, Science and Technology (Grant No. 23500568), Japan.

References

1. Herman BA and Harris Ultrasound in Med. & Biol. **28**(2002)1217.
2. M. Tabaru, *et al.*: J.Med.Ultrasonics, **39**(2012) 137.
3. S. Tanaka, *et al.*:Spring Meeting Acoust. Soc. of Jpn.(2012)1309.
4. S. Sakuma, *et al.*:Spring Meeting Acoust. Soc. of Jpn.(2012)1311.
5. Y. Saito, *et al.*: Jpn. J. Appl. Phys. **44** (2005) 4600.
6. Y. Saito, *et al.*: Jpn. J. Appl. Phys. **45** (2006) 4693.
7. T. Kamakura: *Fundamentals of Nonlinear Acoustics*(AICHI,1996)p. 83.
8. S. Yamazaki: Proc. IUS, UFFC, IEEE (2008) 377.

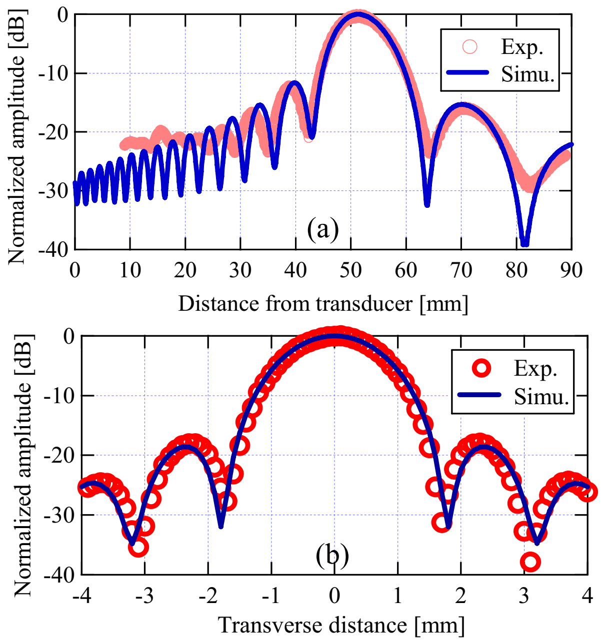

Fig. 1 Sound pressure distributions of experiment and simulation, (a) at central axis, (b) transverse direction on focal point.

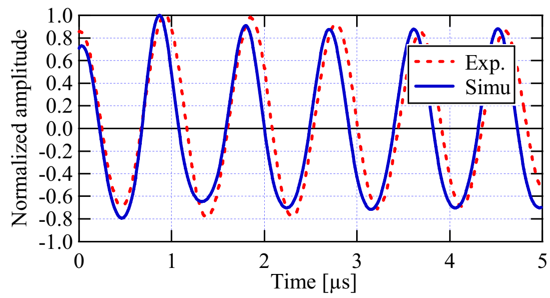

Fig. 2 Waveforms of experiment and simulation at focal point in sound field.

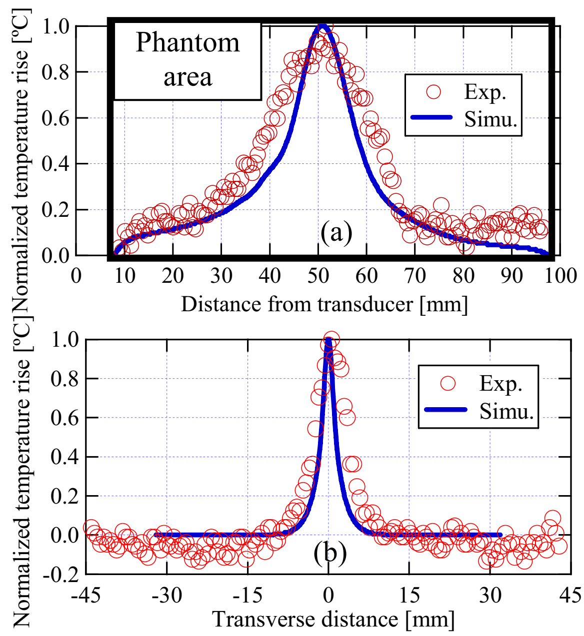

Fig. 3 Temperature rise distribution of experiment and simulation, (a) at central axis, (b) transverse direction on peak temperature rise point.