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Numerical Examination of Bio Heating Using Transducer Array
トランスデューサアレイを用いる生体加熱の数値的検討

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1. Introduction

High intensity focused ultrasound (HIFU), one of hyperthermia, noninvasively coagulates cancer with rapid temperature rise caused by focused ultrasonic waves. Focused ultrasonic energy from HIFU is absorbed in a target of cancer. Then, a temperature of target area is raised up to the range of 50 − 90 °C without damaging the surrounding body tissue.[1)] A concave oscillator is used for HIFU to focus ultrasonic energy on the target. Ultrasonic energy from a concave oscillator is focused on a fixed point. We have proposed a method to focus the ultrasonic energy with an acoustic lens which is exchanged depending on a focal length.[2, 3)] However, it is difficult for both methods to focus the energy on the target near a transducer because its limit of thickness.

In this paper, we proposed a method to focus ultrasonic energy using a phased array transducer which can focus dynamically on close range. The delay phase of the electrical signal is controlled by driving each element. We investigated the temperature rise in the body tissue caused by focused ultrasonic energy using the array transducer.

2. Theory

2.1 principle of phased array transducer

The annular array transducer consists of multi-element as shown in **Fig. 1**. The center of the transducer is taken to be the origin in the three-dimentsional coordinate. The sound wave is radiated along the *z*-axis. The number of the piezoelectric element is N. The distance from n-th element to the center of annular array transducer is D_n as shown in Eq. (1) and to the focal point is l_n as shown in Eq. (2).

$$D_n = (n-1)\,d\,, \tag{1}$$

$$l_n = \sqrt{D_n^2 + F^2}\,, \tag{2}$$

where d is the distance between adjacent elements. The delay phase of applied voltage to n-th element, β_n is the focal distance, l_n multiplied by wave number, k as shown in Eq (3).

$$\beta_n = k l_n\,. \tag{3}$$

When the phase of electrical signal is controlled properly, ultrasonic waves are focused on optional area by superposition of waves from each element according to the Huygen's principle.

2.2 Bioheat Transfer Equation

We investigated the temperature rise and its distribution in a body tissue caused by focused ultrasonic energy using a simulation. The thermal conduction caused by absorption of focused ultrasonic energy is calculated with Pennes's bioheat transfer equation as shown in Eq. (4).[4)]

$$\rho c_t \frac{\partial \tau}{\partial t} = \kappa_t \nabla^2 T - w_b c_b (T - T_b) + Q\,, \tag{4}$$

where T is a temperature distribution in a body tissue, T_b is a temperature of blood, ρ, c_t and κ_t are a density, a specific heat, and thermal conductivity of a body tissue, w_b and c_b are a blood flow and a specific heat of blood, ∇ is gradient operator and Q is the rate of heat quantity per unit volume of a body tissue supplied by a heat source which is caused by absorption of ultrasonic energy. Acoustic intensity is I as shown in Eq. (5). Then, Q is a attenuation coefficient of body tissue, α multiplied by I as shown in Eq. (6).

$$I = \frac{p^2}{\rho c}\,, \tag{5}$$

$$Q = \alpha I\,, \tag{6}$$

where p and c are an acoustic pressure and a velocity of a body tissue. The temperature distribution in a body tissue are obtained by solving Eq. (4) − (6) with satisfactory accuracy.

3. Simulation results

The sound pressure and the temperature distribution in a body tissue were calculated by solving coupled problem among acoustics, piezoelectric, and heat with the finite element me-

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thod (FEM). The phased array transducer was annular, therefore, this simulation model was symmetric with respect to the z-axis. The Parameters used for simulation is given in **Table I**.[5)] The simulation model consisted of piezoelectronic elements, a body tissue which was equability, and a acoustic matching layer made of epoxy resin which was located into elements and a body tissue. Calculating area is cylinder whose radius and height were 30 and 50 mm. The thickness of the acoustic matching layer was 0.6 mm which is one-quarter of wavelength because reflection on a surface was prevented. The number of piezoelectonic elements, N was 13 and the distance between adjacent piezoelectronic elements, d was 1.3 mm. The width and thickness of a piezoelectronic element were 1 and 2 mm. Then, radius of annular array was 16.1 mm. Sinusoidal signals applied to the transducer is generated at a frequency of 1.125 MHz in 20 W.

Figure 2 shows the calculated temperature at the focal point and its distribution. Figure 2(a) and 2(b) show the calculated temperature distributions after driving a transducer for 15 seconds when a focal legth, F is 10 mm and 20 mm. Phased array transducer could focuse optional point in close range and heats a locally body tissue above 60 °C without a serious influence on the surrounding area. The maximum temperature are 63.69 °C and 77.57 °C at points when z is 9.57 and 19 mm, respectively. Figure 2 (c) shows the alteration of temperature at the points of the highest temperature. The result of drinving the taransducer for 15 seconds in 20 W, the temperature at focal point could be raised rapidly above coagulation point, above 60 °C.

4. Conclusion

We proposed a method to focus ultrasonic energy with a phased array transducer which is applicable to treat canser. We investigated the temperature rise and its distribution in a body tissue caused by focused ultrasonic energy using a simulation. As a result of a simulation, it is possible to heat body tissue rapidly above 60 °C and to focus dynamically on optional closer area.

Table I. Parameters of a body tissue

T_b	°C	36
ρ	kg/m3	1,000
c_t	J/(kg °C)	3,770
κ_t	W/m· °C	0.536
w_b	kg/(m^3· s)	7.0
c_k	J/(kg· °C)	4,190
α	Np/(MHz· m)	0.17
c	m/s	1,500

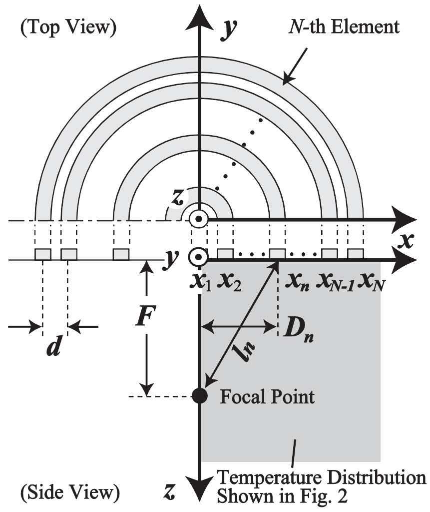

Fig. 1 Schematic geometry of a annular array transducer

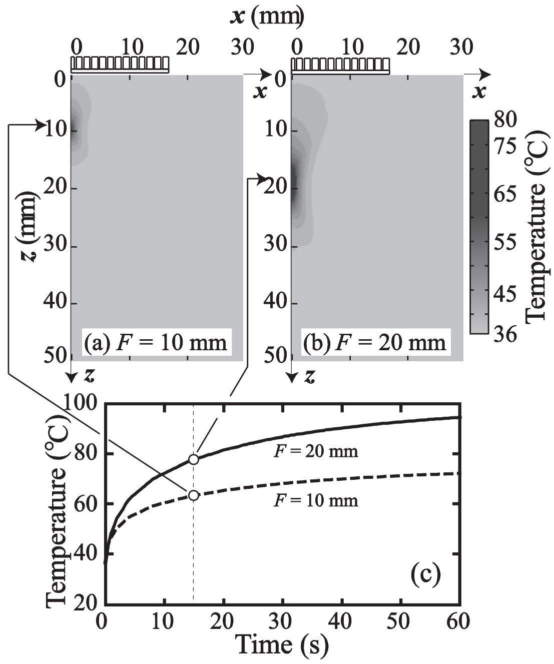

Fig. 2 Calculated temperature at a focal point and its distribution

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