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Phantom made of polyvinyl alcohol for visualization of thermal distribution due to ultrasound

超音波による温度分布可視化用の PVA ファントーム

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1. Introduction

Many studies have been reported to analyze temperature distribution in a tissue-mimicking medium due to ultrasound[1,2]. However, tissue-mimicking medium for temperature distribution analysis should be taken into consideration of the factors such as transparency, durability, and ease of production. Many attempts have been made to develop the tissue mimicking medium that satisfies the factors[3]. In this study, we suggest a gel-type tissue mimicking phantom made of polyvinyl alcohol (PVA) powder, which has excellent properties mentioned above. To visualize thermal distribution in the phantom due to ultrasound, thermochromic film made of liquid cystal is used.

2. Manufacture and experiment

In order to make a gel-type PVA phantom, an appropriate amount of PVA powder is dissolved in distilled water and stirred with heating below the temperature of 80 °C. For coagulation to a gel state, borax solution is added to the completely dissolved PVA solution. In this study, the borax solution of 4 wt.% was 100 g and the PVA solution of 16 wt.% was 2.5 L. Figure 1 shows the system to measure the acoustic characteristics of the PVA phantom, and the sound speed and acoustic attenuation coefficient were estimated as 1507.3 m/s and 1.4548 dB/m/MHz, respectively. The attenuation coefficient was obtained by

$$\alpha_p = \frac{\ln\frac{V_w}{V_p} + \alpha_w l}{fl}. \tag{1}$$

Here, V_w and V_p are the received voltages in water and in the PVA phantom, respectively. The α_w is 0.2 dB/m/MHz, which is the attenuation coefficient in water at room temperature, and the driving frequency of the transducer f is 5.0 MHz.

To measure the thermal conductivity of PVA phantom, the experimental system was constructed as shown in Fig. 2. The thermal conductivity of the phantom k_p can be obtained by the following equation when that of standard specimen k_1 is given.

$$k_p = k_1 \frac{T_3 - T_2}{T_2 - T_1}\frac{d_x}{d_s}. \tag{2}$$

Where T_1, T_2, and T_3 are the temperature of Ch.1, Ch.2, and Ch.3, respectively. The thicknesses and the thermal conductivities of the standard specimen and the PVA phantom are listed in Table I. The measured thermal conductivity of PVA phantom is slightly bigger than that of water 0.6 W/mK at room temperature. The thermochromic film of the response of 1 °C/ms, which is commercialized, was used for the visualization of the temperature change. Figure 3 shows the experimental setup to visualize the temperature distribution generated in the PVA phantom by the focused ultrasound. The focused ultrasonic transducer was fabricated with a PZT piezoelectric vibrator which has 6 cm of both aperture diameter and curvature radius and has 1.12 MHz. The used thermochromic film is a liquid crystal sheet having the length of 7.8 cm, the width of 14 cm, and the thickness of about 0.3 mm. The acrylic container for the PVA phantom was a rectangular parallelepiped having a volume of about 2 L, and a focused ultrasonic transducer was mounted at the bottom of the container. The temperature distribution within the PVA phantom appears on the thermochromic film, which is observed through the transparent PVA phantom and acrylic walls and it is recorded as image data.

3. Results

Temperature distribution in the PVA phantom due to ultrasound radiated from the focused ultrasonic transducer was measured using the system of Fig. 3, as shown in Fig. 4. Figure 4(a) shows that the discoloration pattern appears on the surface of the thermochromic film inserted in the PVA phantom due to the ultrasound. This result shows the highest temperature in the vicinity of the focused area and it is similar to the result of Fig. 4(b) which is the simulation result of the finite element method. The power of 15 W was applied to the ultrasonic transducer for 10 seconds. As an equivalent condition, vibration displacement of about 11.4 nm

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at the surface of the transducer was applied to the simulation. From the two results, it can be seen that the influence of the thermochromic film was very limited because both the temperature distribution and the rising temperature range in the focal region are similar. The real time observation of temperature distribution in the acoustic medium was possible with the sufficiently fast response by using the suggested PVA phantom with the thermochromic film.

4. Summary

In developing a tissue mimicking phantom to visualize the temperature distribution for ultrasonic therapy, a tissue mimicking phantom using PVA gel was proposed in consideration of factors, such as transparency, durability, and ease of production. The temperature distribution in the PVA phantom due to the focused ultrasound was visualized by using the PVA phantom with the thermochromic film. The measurement result showed good agreement with the simulation results. From this result, we can confirmed the effectiveness of the proposed method to visualize the temperature distribution.

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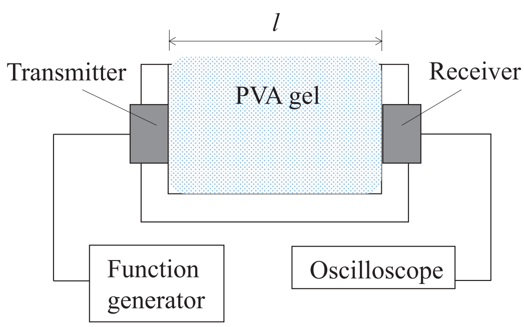

Fig. 1 Experimental setup for measurement of acoustic characteristics.

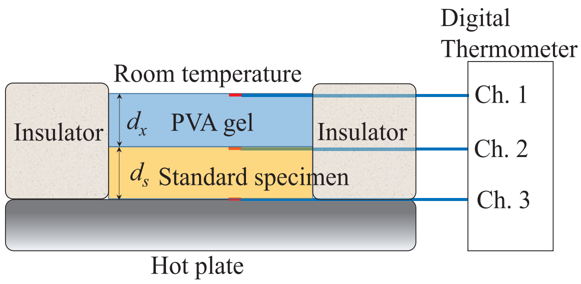

Fig. 2 Measurement system for the thermal conductivity.

Table I. Thermal conductivities and thicknesses of materials.

	Conductivity (W/mK)	Thickness (mm)
Standard specimen	0.083	7.92
PVA phantom	0.736	14.28

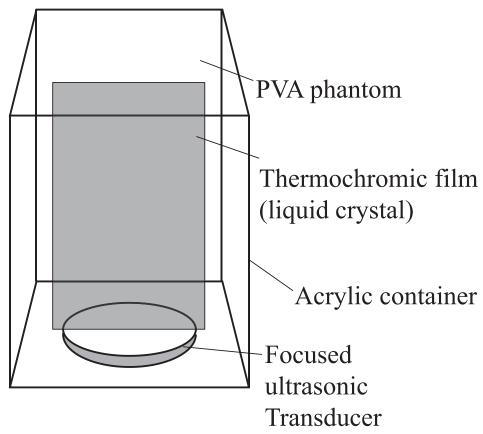

Fig. 3 Experiment system for visualization of temperature distribution caused by two arrayed transducers.

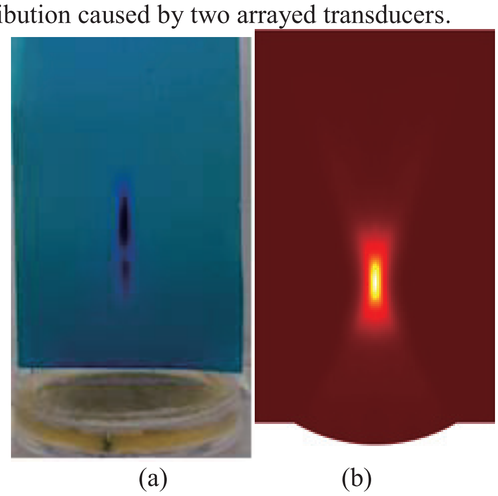

Fig. 4 Temperature distribution due to the focused ultrasonic transducer.
(a) Measurement result and (b) simulation result