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Fundamental study on development of tissue mimicking phantom with acoustic and electrical characteristics

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1. Background

In recent years, there has been ongoing research on the development of quantitative diagnostic techniques and the quantification of diagnostic indicators using medical imaging modalities such as ultrasound, CT, and MRI. The Radiological Society of North America (RSNA) established the Quantitative Imaging Biomarkers Alliance (QIBA) in 2007 to establish various biomarkers, focusing on data acquisition, experimental protocol establishment, and standardization of validation phantoms. Other international organizations like the International Electrotechnical Commission (IEC) are also working on standardization for equipment's accuracy validation phantoms and safety, with attention to electrical property evaluation. However, there is a scarcity of development examples for standard phantoms that encompass multiple physical properties.

This study aims to develop a novel phantom with electrical properties similar to the human liver based on a phantom commonly used for quantitative ultrasound (QUS) investigation. This research included the evaluation of electrical properties for phantoms containing nylon particles used for backscattering coefficient assessment and graphite used for amplitude envelope statistics analysis. The evaluation results of the phantoms were compared with the electrical properties of the liver and fat (alone) for quantitative evaluation of fatty liver as a future clinical application.

2. Materials and Methods

2.1 Measurement Targets

As phantoms 1, 2, and 3, those used primarily to evaluate backscatter coefficients were used. These were made by adding 2 wt% agar powder to ultrapure water and then adding nylon sphere (OGASOL 2002 EXD NAT 1; Arkema) with an average particle size of 10 μm at 1 wt%, 5 wt%, and 10 wt%, respectively. As phantoms 4 and 5, we used those designed for evaluation of the image accuracy of ultrasound systems and for QUS studies. These were created by adding 5 wt% graphite powder and 3 wt% agar to ultrapure water, and phantom 5 additionally contains 20 wt% isopropyl alcohol. [1)] All phantoms have a cylindrical shape with a diameter of 26 mm and a height of 80 mm.

2.2 Electrical Property Evaluation

The phantom was placed inside a cylindrical fixture with electrodes at both ends, and the electrical property evaluation was conducted using the CHEMICAL IMPEDANCE ANALYZER (IM3590, manufactured by HIOKI). Alternating current was applied at 1001 frequency points within the frequency range of 1 kHz to 1 MHz with equal intervals. The resistance and capacitance values were obtained at each frequency. Using the obtained resistance values R [Ω], electrode surface area A [m²], and electrode spacing d [m], the conductivity σ [S/m] was calculated using Equation (1).

$$\boldsymbol{\sigma = \frac{1}{R} \cdot \frac{d}{A}} \tag{1}$$

Using the capacitance C [F], and the dielectric constant of the vacuum $\boldsymbol{\varepsilon_0}$, the relative permittivity ε was calculated using Equation (2). In this case, $\varepsilon_0 \approx 8.854 \times 10^{-12}$.

$$\boldsymbol{\varepsilon = \frac{C}{\varepsilon_0} \cdot \frac{d}{A}} \tag{2}$$

3. Result

Figures 1 shows the speed of sound and attenuation coefficient for each phantom, which were evaluated priori with a single concave ultrasound transducer of 5 MHz center frequency. The speed of sound in the phantom increases with scatter concentration, and isopropyl alcohol also increases the speed of sound. As is well known, the scattering by nylon spheres is stronger than that by graphite powders, and the effect of isopropyl alcohol in increasing the attenuation coefficient can be confirmed.

The mean values and standard deviations of conductivity and permittivity calculated from 15

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measurements of each phantom are shown in **Figs. 2 and 3**. Reference values for liver and fat are also shown in each figure. [2)]

Figure 2 confirms that the higher the volume fraction of nylon sphere, the higher the conductivity. This is assumed to be due to a change in the relative relationship between the distance d between electrodes and the surface area A, as the volume of the conductive medium in the phantom in the fixture decreases as the volume of the non-conductive nylon sphere increases. In phantoms 4 and 5, frequency dependence was observed in the low frequency band. This is due to the influence of graphite, which has conductive properties. It can also be confirmed that the conductivity is decreased by isopropyl alcohol.

From **Fig. 3**, it can be confirmed that the relationship between the magnitude of the relative permittivity of each phantom is inversely related to the conductivity. In phantoms 1, 2, and 3, the larger the volume fraction of nylon sphere, the smaller the volume of the conductive medium, and therefore, the smaller the amount of charge that can be held. In phantoms 4 and 5, the relative permittivity values are reduced by isopropyl alcohol. Compared to the conductivity, the frequency dependence of the relative permittivity of each phantom tends to be close to that of a real human body.

4. Conclusion

To create a new phantom with acoustic and electrical properties close to those of the human liver (normal and fatty liver), the electrical properties of previously developed ultrasound phantoms were evaluated. In particular, there was a large discrepancy between each phantom and the liver in terms of electrical conductivity. This is assumed to be because the liver is composed of various types of tissues, whereas the phantoms do not include properties such as ionic properties and bonding. In the future, we will consider the base material for adjusting the electric properties, taking into account the chemical properties.

Acknowledgment

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References

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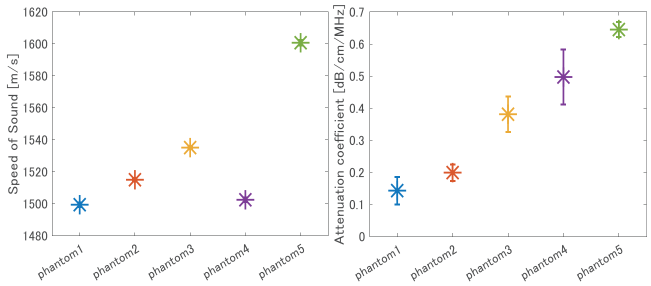

Fig. 1 Speed of Sound (left) and attenuation coeficient (right) of phantoms

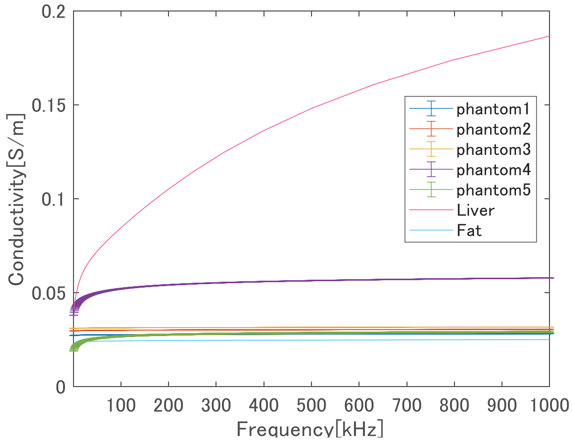

Fig. 2 Frequency dependence of conductivity

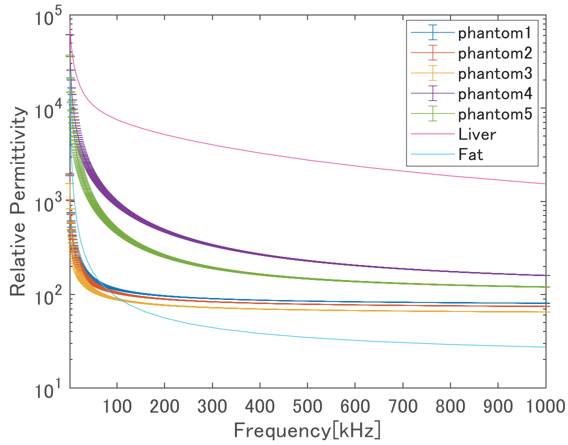

Fig. 3 Frequency dependence of relative permittivity