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Tissue Equivalent Materials and their Applications to Phantoms
生体擬似物質とファントムへの応用

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1. Introduction

There have been developed various ultrasound phantoms, which are essential to quality control of ultrasound scanners; a few characteristics of existing phantoms are even unsatisfied to accomplish the international standard.

New biomimetic soft gel materials for phantoms resolved some of disadvantages such as change in quality with time[1)] and the acoustic properties that should be identical with specifications of IEC International Standard 61685[2)] shown in **Table1**, which are practically valid and acceptable as international standards. We have adopted a new approaching method to be able to reproduce accurately specified acoustic properties.

Table I Parameters of tissue-mimicking material defined by IEC Standard.

Sound velocity	(1540 ± 15) m s^{-1}
Attenuation (one-way passage)	(0.5 ±0.05) × 10^{-4} × f dB m^{-1} Hz^{-1}
Attenuation	(0.75 ±0.05) × 10^{-4} × f dB m^{-1} Hz^{-1}
Characteristic acoustic impedance	(1.60 ±0.16) × 10^{6} kg m^{-2} s^{-1}
Backscatter coefficient	(1 to 4) × 10^{-28} × f^4 m^{-1} Hz^{-4} sr^{-1}

2. Method

The following shows the production method of new biomimetic soft gel materials.

1) We selected the even sized particles that are spherical particles with a precisely controlled diameter. in stead of uneven ones, which are used in existing hydrogel materials[3)]. For example, Polymethyl methacrylate (PMMA) spherical particles completely conformed to the industrial standard were dispersed in the gel (SPUG; Segmented Polyurethane Gel). A SEM image of powder dispersed in the gel is shown in **Fig.1**.

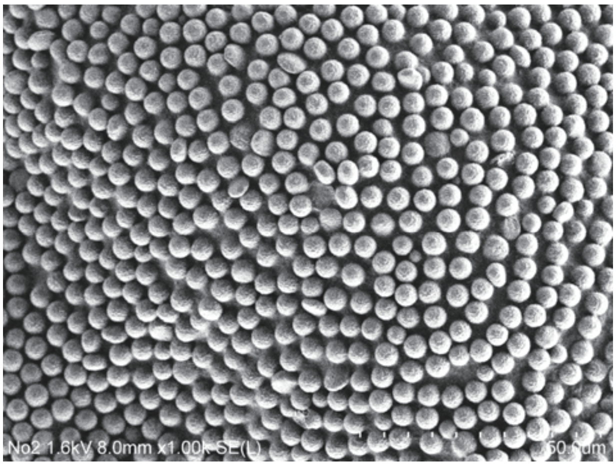

Fig.1. A SEM image of PMMA spherical particles

2) The acoustic velocity, the density, the diameter and the volume % of particles were determin. In this test, the optimum dispersion gel models could be found by a computer simulation, which is based on the analytical model of acoustic velocity, attenuation and backscatter coefficient of spherical particles dispersed in the gel[4)~6)], and the results were appropriately verified by the experiments.

Intensive calculations of the acoustic properties based on theoretical models are efficient on reduction of the testing times. For the particles in an industrial use their particle size and physical properties are precisely assured by control of manufacture.

Consequently, it is now possible to calculate the acoustic quantities of the properties with a considerable accuracy.

Acoustic velocity C_0, attenuation constant A and back scattering coefficient S of the tissue mimicking material are given by the following

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equation.

$$C_0^2 = \frac{1}{(d_1 u + d_2(1-u))(k_2 u + k_1(1-u))} \quad (1)$$

where u=concentration by volume of particles, d_n=density, k_n=adiabatic compressibility and indexes n=0,1,2 corresponding to suspension, gel and particle respectively.

$$A = \frac{k}{2v}\frac{(1-d_1/d_2)^2}{d_1/d_2} w_0 \frac{(w/w_0)^2}{(1+(w/w_0)^2)}\frac{M}{M_e} \quad (2)$$

where $w_0=R_f / M_e$, $w = 2\pi f$, f=frequency of sound, v=acoustic velocity of the material, d_1=density of gel, d_2=density of particles, k=volume of particles, M=mass of a particle. Friction force constant R_f and equivalent mass of particle M_e are given by the following equations.

$$R_f = 6\pi a g\left(1+\sqrt{\frac{d_1}{2g}}\,a\sqrt{w}\right), \quad M_e = M + m\left(\frac{1}{2}+\frac{9}{4a\sqrt{d_1/2g}\,\sqrt{w}}\right),$$

where g=coefficient of viscosity, a=radius of a particle, m=mass of gel with equivalent volume of a particle.

$$S = \frac{1}{12}\pi K^4 a^3 u(1-u)^4\left(\frac{d_k}{k-d_d/d}\right)^2\left(\frac{0.37}{1+(1.06(1-u)Ka)^2}\right) \quad (3)$$

where $K^2=\omega^2 kd$, $d_k=k_1-k_2$, $d=d_2-d_1$, $k=k_1+ud_k$, k=adiabatic compressibility, d=density of the material.

A typical example of calculations of attenuation on the in the gel(SPUG) is shown in **Fig.2.**

An optimum attenuation characteristic is determined by the result. Or, attenuation constant of the material dispersed with powder of diameter 5 μ m. is proportional to the frequency and that is fulfilled the characteristic required in the IEC standard.

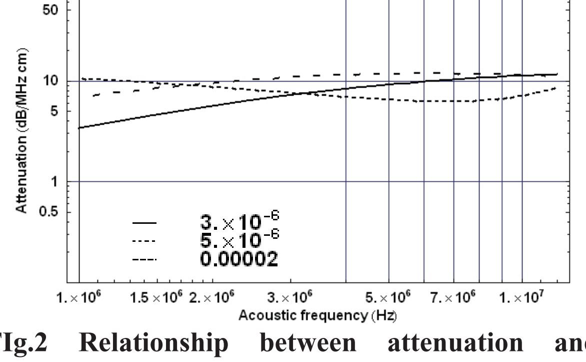

FIg.2 Relationship between attenuation and frequency. Parameters are the diameter of particles.

3. Experimental results

Tissue mimicking materials were manufactured on optimum solutions of the material design. A experimental result for the relation between attenuation constant and acoustic frequency is shown in **Fig.3.**

The attenuation characteristic agrees with the parameter defined by IEC standard.

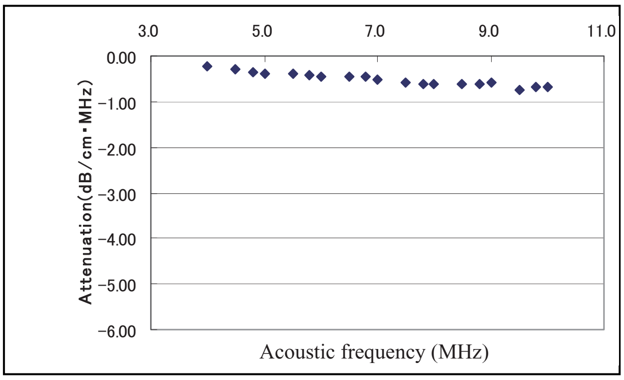

Fig.3 Relation between coefficient of attenuation and acoustic frequency in the tissue mimicking material for a phantom.

4. Results

The adoption of the following materials to the phantom was discussed in this study: (SPUG; Segmented Polyurethane Gel). 1-10 micron PMMA particles. It was conformed that experimental results agree with the calculated values under some conditions.

Optimum solutions of the material design for phantoms have been obtained by using eqs. (1), (2) and (3).

The phantoms with new biomimetic soft gel materials that have the similar attenuation coefficient to the liquid living body over the frequency band-width ranging from 1 to 10 MHz, with a long-term stability and reliable acoustic properties specified by IEC international standard[2] have been developed.

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