

Ultrasonic properties of a four years old tissue-mimicking material

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Abstract: This paper presents the metrological study of long-term stability of the ultrasonic properties of a tissue-mimicking material (TMM) manufactured in 2013. The thickness, speed of sound and attenuation coefficient of TMM were estimated by the pulse-echo technique. The Student's paired t-test was applied and the averages of the speed of sound and the attenuation coefficient in the four years-old TMM did not differ statistically from the reference values presented in the standard.

Keywords: long-term stability, phantom, ultrasonic properties, metrology

1. INTRODUCTION

Tissue-mimicking materials (TMM) have been manufactured for characterization, performance testing and calibration of ultrasonic diagnostic and physiotherapy equipment. According to the standard IEC 60601-2-37 [1], the TMM intended for these applications shall have thermal and ultrasonic properties similar to human soft tissue. The most critical ultrasonic properties of TMM are the speed of sound, acoustic impedance, attenuation coefficient, backscattering coefficient and nonlinearity parameter [2].

According to Culjat et al. [2], the longevity is also important for TMM, or the period of time over which the ultrasonic and mechanical properties are stable and consistent. Longevity can vary widely, depending on the selected materials and preparation technique.

That said, there are some works in literature concerning for long-term stability of mechanical, elastic and ultrasonic properties of TMM [2]-[5].

Soft tissues are composed of muscles, tendons, ligaments, fascia, fat, fibrous tissue, synovial

membranes, nerves and blood vessels [2]. There are a variety of soft tissue-mimicking materials, as agarose-based, gelatin-based, zerdine, among others.

In 2013, Petrella et al. [6] fabricated agar TMM to study the influence of subcutaneous fat in surface heating of ultrasonic diagnostic transducers, following the recipe described in [1]. After that, Souza et al. [7] present a more detailed standard operating procedure (SOP) to prepare agar TMM. Since then, some works in the literature [8][9] used the SOP described in [7] for fabrication of agarose phantoms with different objectives.

It is important to mention that the standard [1] describes the way the TMM should be stored and maintained, as well as the ultrasonic and thermal properties of tissues and materials. Also according to [1], TMM shelf life if it is preserved without air contact should be at least one year.

Considering the foregoing, this paper presents the metrological study of long-term stability of agarose phantom's ultrasonic properties (speed of sound and attenuation coefficient) fabricated in

2013 (see [6]). This study was performed by comparing the ultrasonic properties of a four years-old TMM's [6] with those described in [1].

2. MATERIALS AND METHODS

2.1. Agar phantom

The soft TMM proposed in [1] has appropriated ultrasonic properties similar to that of human soft tissue and are presented in Table 1. The TMM fabricated in 2013 is presented in figure 1a.

Table 1. TMM's ultrasonic properties proposed in [1].

Speed of sound [m s ⁻¹]	Attenuation Coefficient [dB cm ⁻¹ MHz ⁻¹]
1540	0.5

2.2. Measurement system

The measurement system was composed by: an arbitrary waveform generator model 33250A (Agilent, USA), an oscilloscope model DSO-X 3012A (Agilent, USA), a 5 MHz central frequency transducer model A309S (Olympus-NDT, USA), a cylindrical water tank (Ø 300 mm × 110 mm) filled with deionized water, and a stainless steel cylindrical reflector (Ø 63 mm × 10 mm). A positioning system with three linear and two goniometric stages was used for transducer alignment to maximize the ultrasonic reflected pulse.

2.3. Measurement procedure

The pulse-echo technique was used to perform the speed of sound and attenuation coefficient measurements. The signals were acquired using the oscilloscope, and the time of flight measurements were carried out using the oscilloscope's electronic cursors. The transducer (T_X) was positioned pointing directly and normal to the front surface of reflector (stainless steel) to acquire a reference signal. Then, the time of flight in the water (t_w), without the TMM, was measured (see figure 1b for illustrative representation).

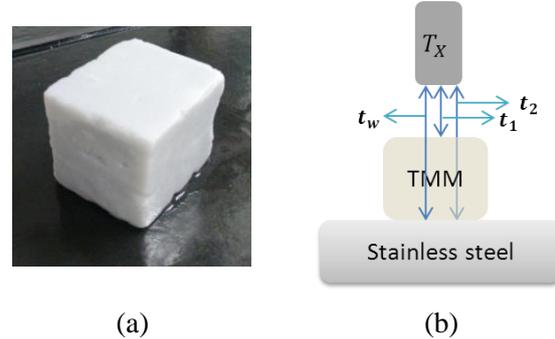


Figure 1. (a) Agar phantom fabricated in 2013 (42 mm × 49 mm × 42 mm). (b) Pulse-echo technique.

Subsequently, for speed of sound calculation, the time of flight on the surface of the TMM (t_1) and the time of flight in reflector with the TMM inserted (t_2) were measured (see figure 1b). For the attenuation coefficient calculation, besides all procedure previously described, it was necessary to measure the amplitude of the signals mentioned.

2.4. Measurement uncertainty

The measurement uncertainty was expressed based on the BIPM/JCGM:100 (GUM) [10]. The sources of uncertainty considered on the measurement of the speed of sound and attenuation coefficient are described in 2.4.1 and 2.4.2.

2.4.1. Speed of sound

The speed of sound (c) is calculated by:

$$c = \frac{2 \cdot d}{(t_2 - t_1)} \quad (1),$$

in which c is the speed of sound, d is the thickness of the TMM in meters and is calculated by (2):

$$d = c_w \cdot \left(\frac{t_w - t_1}{2} \right) \quad (2),$$

in which c_w is the speed of sound in the water and is calculated as a function of temperature as described in [11]. The contribution of each source of uncertainty is presented in the Ishikawa's diagram in figure 2.

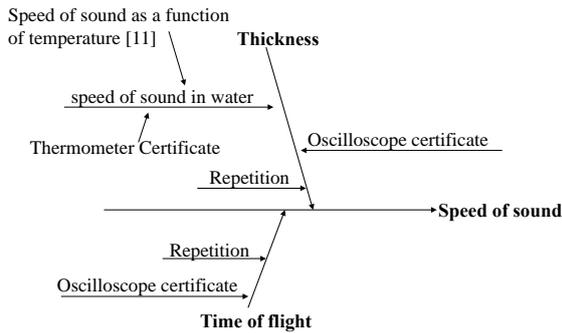


Figure 2. Ishikawa's diagram presenting the sources of uncertainty for speed of sound.

The following sources of uncertainty were considered with respect to the measurement of the group velocity of the TMM: the uncertainty of the temperature measured during the water bath experiments ($0.01\text{ }^{\circ}\text{C}$), leading to an uncertainty of 0.03 m s^{-1} in the speed of sound; the uncertainty of the determination of the ultrasound propagation velocity in water (0.2 m s^{-1}) [11]; the uncertainty of the oscilloscope time base ($2.4 \times 10^{-8}\text{ s}$), given an uncertainty of 0.7 m s^{-1} ; the uncertainty of the measurement of phantom's thickness (0.02 mm), contributing with an uncertainty of 0.7 m s^{-1} ; and the dispersion of speed of sound measurements led to an uncertainty of 0.091 m s^{-1} . By combination of these figures, the combined uncertainty estimated for speed of sound was 1.0 m s^{-1} .

2.4.2. Attenuation coefficient

In a simple way, attenuation coefficient was determined as the ratio between the amplitudes of the signals reflected over the reflector with and without the TMM. The reflection coefficient of the reflector, as well as the attenuation in the water, was considered in calculation.

The contribution of each source of uncertainty in estimating the attenuation coefficient is presented in the Ishikawa's diagram in figure 3, and the following sources of uncertainty were considered: the uncertainty of the attenuation coefficient in the water ($4.4 \times 10^{-4}\text{ dB cm}^{-1}$); the uncertainty of the TMM thickness (0.02 mm),

leading to an uncertainty of $1.2 \times 10^{-3}\text{ dB cm}^{-1}$; the reflection coefficient in the stainless steel cylindrical reflector, which accounts for an uncertainty of $5.8 \times 10^{-5}\text{ dB cm}^{-1}$; the uncertainty of the oscilloscope time base ($2.4 \times 10^{-8}\text{ s}$), given an uncertainty of $2.2 \times 10^{-4}\text{ dB cm}^{-1}$; the uncertainty concerning the signal amplitude measurement ($5.2 \times 10^{-3}\text{ V}$), contributing with an uncertainty of $1.8 \times 10^{-3}\text{ dB cm}^{-1}$. Finally, the dispersion of attenuation coefficient measurements led to a combined uncertainty of 0.028 dB cm^{-1} , which was the most important source of uncertainty.

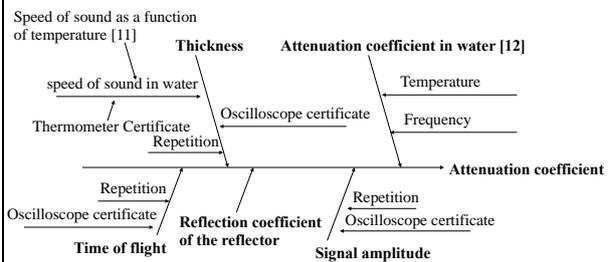


Figure 3. Ishikawa's diagram presenting the sources of uncertainty for attenuation coefficient.

2.4. Significance t-test

The t-test was applied to assess the statistical significance between the measurement results of the speed of sound and attenuation coefficient concerning the values presented in [1].

One should consider if the mean of measurements (X) differ significantly from the reference value (μ_0) (table 1). For such, the null hypothesis is given by $H_0 : X = \mu_0$ and the alternative hypothesis is given by $H_a : X \neq \mu_0$.

The t-test is calculated by [13]:

$$t_{calc} = \frac{X - \mu_0}{u_c} \quad (3),$$

in which t_{calc} is the test statistic and u_c is the combined uncertainty. Based on a defined significance level ($\alpha = 0.05$) and the number of effective degrees of freedom, a test critical value (t_{crit}). If $t_{calc} < t_{crit}$, H_0 can not be rejected.

3. RESULTS

The phantom's thickness (e) was estimated as 42.817 mm ($U = 0.066$ mm; $p = 0.95$; $k = 2.2$). Table 2 provides the result for speed of sound (c), whilst table 3 presents the result for the attenuation coefficient (a_c). For both, type A (u_A) and type B (u_B) standard uncertainties, coverage factor (k) and expanded uncertainty (U) are also presented. Table 4 shows the result of the t-test.

Table 2. Result for the speed of sound measurements carried out on the four years old TMM.

c [m s ⁻¹]	u_A [m s ⁻¹]	u_B [m s ⁻¹]	k	U [m s ⁻¹]
1538.9	0.091	1.017	1.96	2.0

Table 3. Results for the attenuation coefficient measurements carried out on the four years old TMM.

a_c [dB cm ⁻¹]	u_A [dB cm ⁻¹]	u_B [dB cm ⁻¹]	k	U [dB cm ⁻¹]
2.573	0.028	0.003	3.18	0.091

Table 4. Significance t-test.

	μ_0	X	t_{calc}	t_{crit}	$t_{calc} < t_{crit}$
c	[m s ⁻¹]		1.12	1.96	Yes
	1540	1538.9			
a_c	[dB cm ⁻¹]		2.56	3.18	Yes
	2.5	2.573			

4. DISCUSSIONS AND CONCLUSION

There is no statistical evidence to reject the hypothesis that the velocity is 1540 m s⁻¹ ($\alpha = 0.05$). In other words, the mean of measurements of the speed of sound in the four years old TMM does not differ statistically from the reference value in the standard. In turn, the same occur with the attenuation coefficient, where t_{calc} was lower than t_{crit} , indicating that the mean and the reference value do not differ significantly.

Glycerol is responsible for provide the speed of sound required to the TMM, while the attenuation coefficient is determined by the concentration of 0.3 mm alumina (Al₂O₃).

Taking into account the TMM was maintained without air contact in the solution proposed by [1] (water and glycerol) over the last four years, and based on the results, one can conclude that the TMM's shelf life, if it is adequately preserved, can be larger than two years as described in [1].

5. REFERENCES

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