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Ultrasound diagnostics of the patient's superficial tissues

© I.A. Shvetsov[1], N.A. Shvetsova[1], N.A. Kolpacheva[2], A.N. Rybyanets[1]

[1] Southern Federal University, Rostov-on-Don, Russia
[2] Don State Technical University, Rostov-on-Don, Russia
E-mail: arybyanets@gmail.com

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A new method of ultrasonic examination of the superficial tissues of a patient *in vivo* has been proposed. The design of ultrasonic measuring module for complex non-invasive diagnostics of the physiological conditions and processes in the superficial tissues of a patient has been developed. Precise measurements of the speed and attenuation of ultrasonic waves were made using the echo-pulse and transmission methods. An experimental verification of the developed ultrasonic method was carried out on reference solutions and superficial tissues of the patient.

Keywords: ultrasound diagnostics, echo-pulse method, superficial tissues, ultrasonic diagnostic module, sound speed, attenuation coefficient.

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The use of ultrasound as a valuable diagnostic and therapeutic agent has now become so widespread in certain fields of clinical medicine that it may be considered integral to proper medical treatment of patients [1–3]. Until quite recently, the key objective of measurements of the sound velocity in biological tissues in medical applications consisted in collecting the data for calibration of sonographic visualization systems. However, it has now become evident for many research groups that the sound velocity is a highly informative specific tissue parameter in itself [1]. The acoustic characteristics of biological tissues were analyzed thoroughly in [4–7].

Attenuation (i.e., total acoustic energy loss in biological tissues) is specified by the combined influence of refraction, reflection, scattering, and absorption of ultrasound. Data on the variations of velocity, acoustic impedance, absorption, scattering, and attenuation within a certain tissue are used in practice to characterize its structure. It should be noted that the studies into attenuation of ultrasonic waves in various biological media and tissues appear to be exceptionally complex. Thus, it may be concluded that the sound velocity is better suited for the role of a fundamental parameter of biological tissues than the attenuation coefficient, which depends, to a certain extent, on variations of the sound velocity. At the same time, relative measurements of the attenuation coefficient are rather informative in regard to variations of the structure and the composition of a biological tissue occurring under the influence of physiological and pathophysiological factors and therapeutic treatment.

Since a conventional standard is lacking, calibration testing of an instrumentation system may be performed by conducting ultrasonic measurements for materials with well-known parameters and reproducible measurement results. Distilled water and aqueous solutions of ethyl alcohol are the media used most commonly in test measurements of the sound velocity.

A number of different methods for measuring the sound velocity have already been developed, although many of them are hardly applicable to biological tissues. In fact, methods for *in vivo* tissue measurements are now only beginning to shape up [8–10]. Owing to the deformation and size variation of the studied soft tissue, measurements of individual segments and local body regions are hard to perform using standard ultrasonic techniques and transducers [9]. Thus, it is fair to say that novel ultrasonic methods for examination of the status of biological tissues and physiological processes occurring in them in the process of therapeutic treatment of a patient are much needed.

In the present study, we propose a new method and a versatile design of an ultrasonic diagnostic module for non-invasive *in vivo* examination of the status of superficial tissues (skin, subcutaneous adipose tissue) in an arbitrary body region of a patient and physiological processes occurring in them.

The measurement setup consisted of a LeCroy Wave Surfer422 digital oscilloscope, a Panametrics (Olympus) 5077 PR pulser/receiver, and the constructed ultrasonic diagnostic module. This module was designed so as to provide temporal fixation of the studied superficial tissue (via vacuum suction) and perform simultaneous measurements of the velocity and attenuation of ultrasonic waves. It had the form of a plastic cup, which was connected to a vacuum system, with connector cables and an ultrasonic transducer mounted inside it (Fig. 1). The transducer was a cylinder with outer diameter $D = 64$ mm, a wall thickness of 2 mm, and a height of 5 mm fabricated from a piezoceramic material (TsTS-19) of the following composition: $Pb_{0.95}Sr_{0.05}(Zr_{0.53}Ti_{0.47})O_3+1\%Nb_2O_5$ [11,12]. This

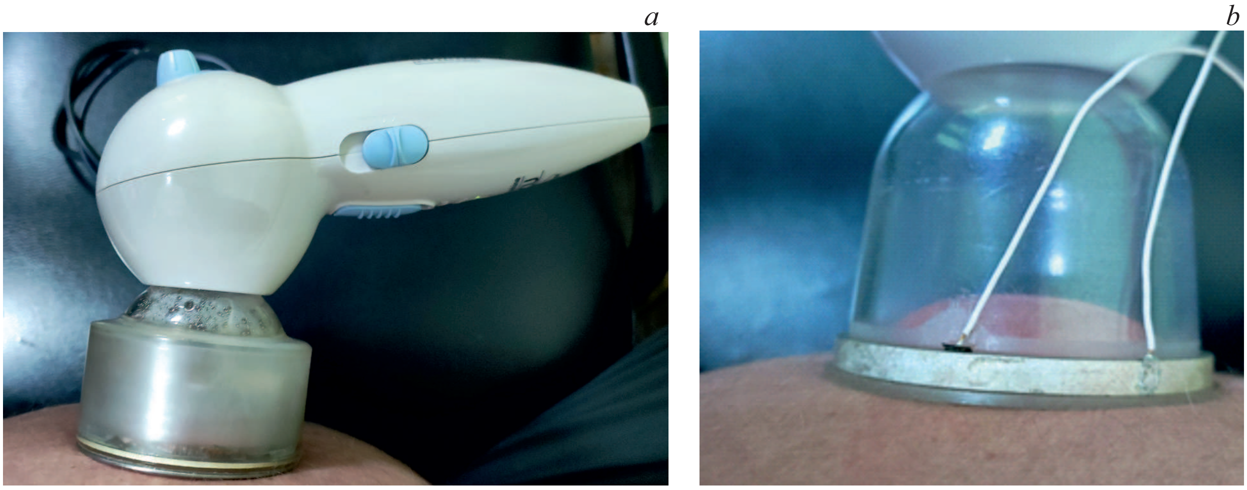

Figure 1. Ultrasonic diagnostic module for examination and monitoring the condition of superficial tissues (*a*) and illustration of the vacuum tissue fixation inside a cylindrical ultrasonic transducer (*b*) in the process of *in vivo* measurement of the ultrasound velocity and attenuation.

transducer was connected to the input terminals of the pulser/receiver and the oscilloscope.

The cylindrical ultrasonic transducer was used both as an emitter and as a receiver of ultrasonic waves. The velocity of propagation of ultrasonic waves in reference solutions and superficial tissues was determined using the transmission and echo-pulse methods by measuring the time of propagation of a probing ultrasonic pulse through the studied medium. Following measurement designs with a known fixed distance between two given planes, the developed transducer measured both the single passage time (transmission mode) and the overall passage time of ultrasonic pulses that undergo multiple rereflections from the inner surface of the cylindrical transducer (echo-pulse mode).

The maximum error of pulse measurements of the signal propagation time based on the time delay recorded with an oscilloscope may be reduced to 0.5% [1].

In order to enhance the measurement accuracy, we also used the method of relative measurements with reference solutions for calibration of the ultrasonic transducer. The error of such measurements of the sound velocity with distilled water used as a reference did not exceed 0.03% [1,2].

The resulting accuracy and error of determination of the sound velocity in biological tissue samples depend substantially on the correctness of determination of the sound path length in the studied sample. It often turns out to be rather hard to determine the path length in relative measurements. The design of the developed diagnostic module provides for vacuum fixation of biological tissues inside the cylindrical ultrasonic transducer with given diameter D and ensures accurate determination of the path length and velocity of ultrasound $V = nD/t_n$, where t_n is the passage time of ultrasonic pulses that were rereflected n times.

Table 1. Sound velocity in distilled water measured at different temperatures

Water temperature,°C	Sound velocity, m/s
50	1564.5
45	1555.2
40	1509.4
35	1500.0
20	1474.9

Prior to *in vivo* measurements for superficial tissues of a patient, the diagnostic transducer was calibrated with a reference solution (distilled water). In order to perform this calibration, the transducer was introduced into a heated chemical vessel filled with distilled water and fitted with a thermocouple for temperature monitoring. An excitation pulse with its length equal to half a period of the resonance frequency (1 MHz) was fed from the pulser/receiver to the cylindrical piezotransducer, and transmission and successive echo signals received by the same transducer were recorded by the digital oscilloscope.

Examples of oscilloscope records obtained in measurements of the sound velocity and attenuation with the use of transmission and echo-pulse techniques in distilled water at a frequency of 1 MHz are shown in Fig. 2.

The measured values of sound velocity in distilled water at different temperatures are given in Table 1. The obtained results agree well with literature data [2,4].

In vivo measurements of the sound velocity and the attenuation of ultrasonic waves in superficial tissues were performed in different body regions of a patient with the use of the precalibrated diagnostic transducer. Examples of oscilloscope records obtained in measurements of the sound

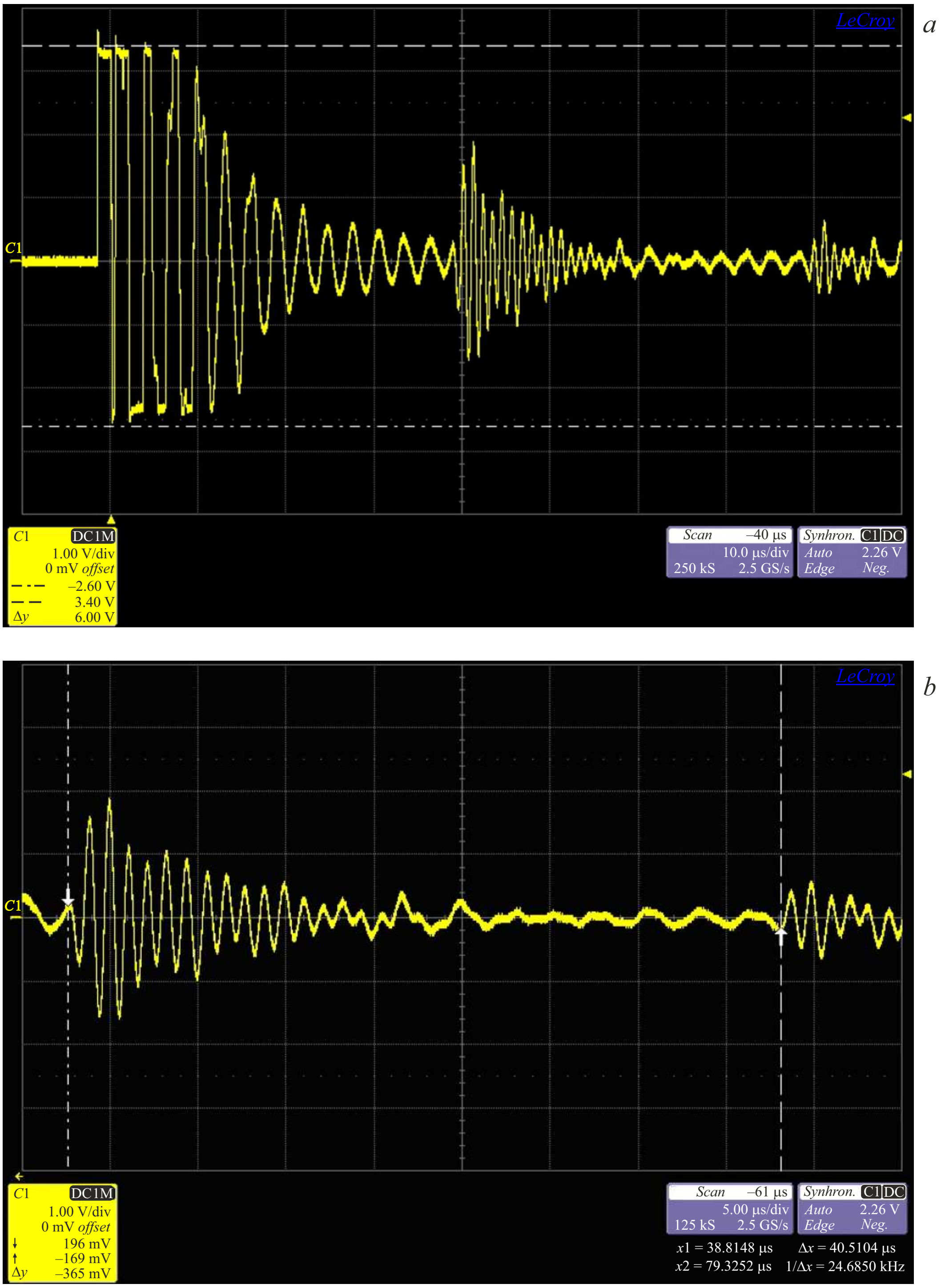

Figure 2. Oscilloscope records of excitation, transmission, and echo pulses in measurements of attenuation (*a*) and velocity (*b*) of sound in distilled water at a frequency of 1 MHz at room temperature.

velocity and attenuation in the abdominal region of the body of a patient are presented in Fig. 3.

The values of sound velocity in superficial tissues of a patient measured at different temperatures are listed in Table 2. These measurements were repeated at least three times at each temperature with a repetition period of 5 min to allow for superficial tissue recovery after vacuum suction. The reproducibility of results did not exceed the measurement error.

The body was heated through the transparent transducer cup by an infrared heater. The body surface temperature was monitored with a built-in thermocouple. It should be

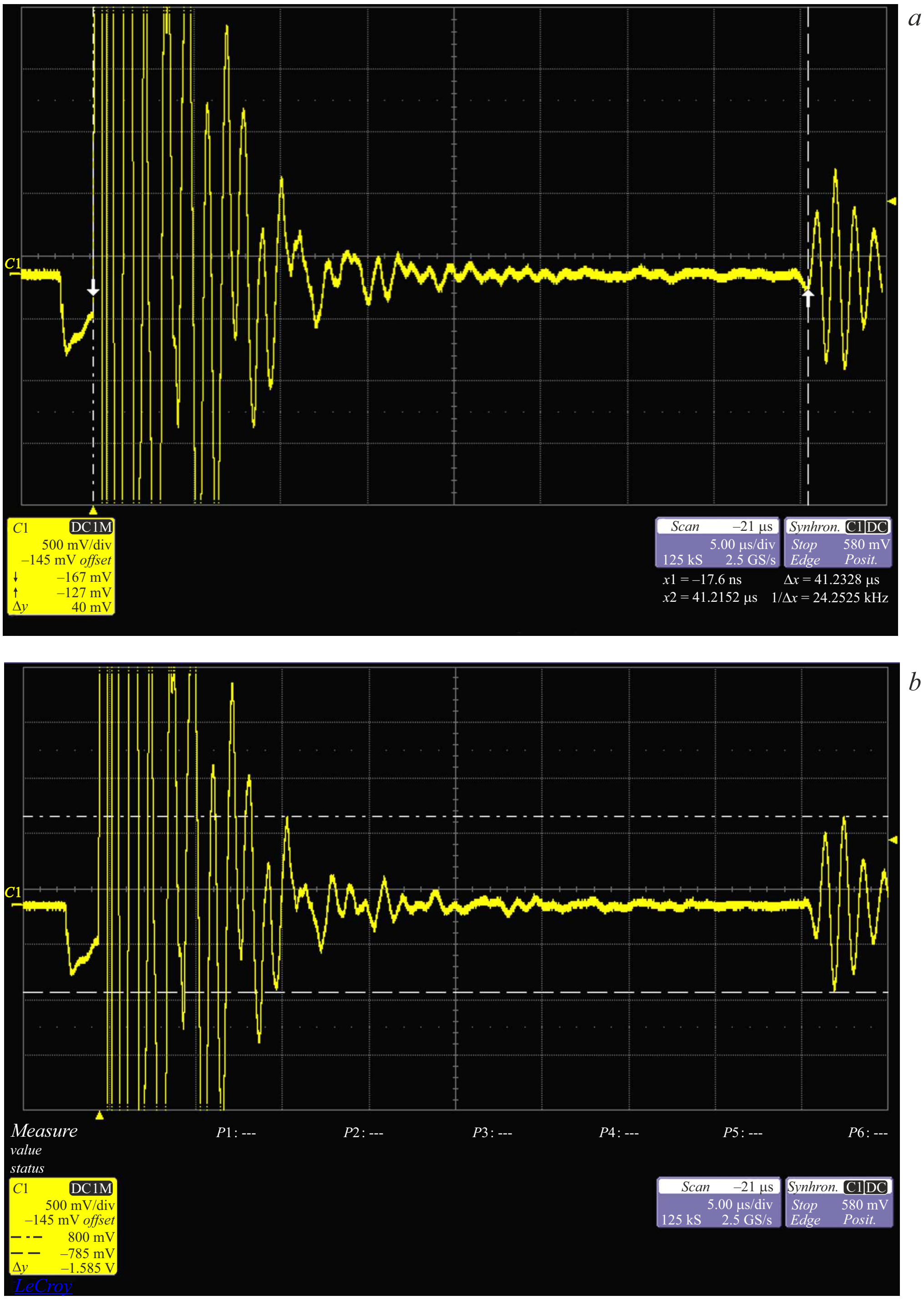

Figure 3. Oscilloscope records of excitation and transmission pulses in *in vivo* measurements of velocity (*a*) and attenuation (*b*) of sound at a frequency of 1 MHz in the abdominal region of the body of a patient.

noted that ultrasonic waves produced in experiments with the current configuration of the diagnostic transducer are localized completely in a 10-mm-thick surface layer (i.e., in the skin and subcutaneous adipose tissue). In complete agreement with literature data [1,2], the velocity of sound in adipose tissue is lower than its velocity in water and is characterized by a negative temperature coefficient.

The current configuration of the diagnostic module cannot be used to measure the absolute value of attenuation, since the primary contribution to the measured attenuation (1.46 dB/cm) is produced by divergence of the acoustic beam and rereflections inside the transducer rather than by attenuation in the medium (0.002 dB/cm for water at a frequency of 1 MHz). However, any changes in the

Table 2. Sound velocity in superficial tissues of a patient measured in different body regions at two fixed temperature values

Body temperature, °C	Sound velocity, m/s	
	Abdominal region	Thigh
36	1447.9	1449.6
40	1438.0	1439.7

temperature of a body and the state of its structural components induce measurable variations of the sound velocity and the relative attenuation of an ultrasonic wave. In addition, the velocity and attenuation of ultrasound in biological tissues change drastically under therapeutic treatment, thus serving as indicators of physiological processes and modifications of the tissue structure and composition (lysis of adipose tissue, dehydration, necrosis, coagulation, blood filling) [2,3].

This provides an opportunity to use the developed method and the ultrasonic diagnostic module for non-invasive diagnostics and monitoring of superficial tissues of patients with various diseases and for monitoring and evaluating the efficiency of physiotherapy treatment and other types of therapeutic intervention.

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Compliance with ethical standards

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Informed voluntary consent was obtained from each study participant.

Conflict of interest

The authors declare that they have no conflict of interest.

References

[1] C. Hill, J. Bamber, G. ter Haar, *Ultrasound in medicine. Physical bases and application* (Wiley, N.Y., 2002)..

[2] G.R. ter Haar, Prog. Biophys. Mol. Biol., **93**, 111 (2007). DOI: 10.1016/j.pbiomolbio.2006.07.005

[3] A.N. Rybyanets, in *Piezoelectrics and related materials: investigations and applications*, ed. by I.A. Parinov (Nova Science Publ., Inc., N.Y., 2012), ch. 5, p. 143–187.

[4] E.I. Carstensen, in *Ultrasonic tissue characterization II*, ed. by M. Linzer, NBS Special Publication 525 (National Bureau of Standards, Washington, 1979), p. 29–40.

[5] F. Dunn, W.D. O'Brien, in *Ultrasound: its application in medicine and biology*, ed. by F.J. Fry (Elsevier, Amsterdam, 1978), ch. 3, p. 393.

[6] R.L. Johnston, S.A. Goss, V. Maynard, J.K. Brady, L.A. Frizzell, W.D. O'Brien, Jr., F. Dunn, in *Ultrasonic tissue characterization*, ed. by M. Linzer, NBS Special Publication 525 (National Bureau of Standards, Washington, 1979), p. 19–27.

[7] F.A. Duck, *Physical properties of tissue* (Academic Press, London, 1990), p. 346.

[8] G.A. Cortela, W.A.C. Pereira, C. Negreira, in *IEEE 2019 Global Medical Engineering Physics Exchanges/ Pan American Health Care Exchanges (GMEPE/PAHCE)* (IEEE, 2019), p. 1. DOI: 10.1109/GMEPE-PAHCE.2019.8717326

[9] A Leydier, J Mathieu, G. Despaux, Measurement Sci. Technol., **20**, 095801 (2009).
DOI: 10.1088/0957-0233/20/9/095801

[10] R. Martınez-Valdez, V.H. Contreras, M.A. Vera, L. Leija, Phys. Procedia, **70**, 1260 (2015).
DOI: 10.1016/j.phpro.2015.08.280

[11] A.N. Rybyanets, in *Advanced materials: manufacturing, physics, mechanics and applications*, ed. by I.A. Parinov, S.-H. Chang, V.Yu. Topolov. Springer Proceedings in Physics (Springer, Cham, 2016), vol. 175, ch. 15, p. 211–228.
DOI: 10.1007/978-3-319-26324-3

[12] S.A. Shcherbinin, I.A. Shvetsov, A.V. Nasedkin, N.A. Shvetsova, A.N. Rybyanets, Ferroelectrics, **539**, 117 (2019). DOI: 10.1080/00150193.2019.1570020