Development of the stable ultrasound phantoms for superficial human tissue investigation

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Introduction. During the past three decades ultrasound scanning has become an important diagnostic tool in dermatology [1, 2]. In dermatology high frequency (mostly in the rage from 15 to 25 MHz) ultrasound systems are used. Transducer's center frequency has a direct effect on image resolution.

Ultrasound technologies in dermatology are used for the assessment of tumoral and inflammatory processes of the skin. Promising results were obtained for the assessment of peripheral lymph nodes [1, 2]. Ultrasonography has a potential to become a promising technique for detecting early signs of diabetic foot ulceration [3].

Biological phantoms are very useful to be used for controlled experiments in biomedical ultrasound [4]. Phantoms are commonly used for the development of imaging systems and evaluation of image processing algorithms. A tissue-mimicking ultrasound phantom emulates important ultrasonic properties of biological tissue (ultrasound velocity, attenuation) for the purpose of providing more clinically realistic imaging environments [5].

The purpose of this study was to develop the superficial tissue mimicking phantoms with inclusions located at different depths. In order to declare that these phantoms are suitable for the superficial tissue mimicking, we verified the phantoms with an ultrasonography tool.

Materials and methods. It has been reported that tissue-mimicking phantoms made from silicones or gels have similar mechanical and acoustic properties as soft tissue [6].

A new elastomer recently was designed specifically for ultrasonic inspection applications [7]. Acoustic impedance of the material is nearly the same as water and its attenuation coefficient is lower to compare with many plastics [7]. Therefore, such material could be used for development of phantoms possessing different shapes and compositions.

In this study two different long time-duration phantoms were manufactured. In our experiments, silicone rubber sheets (Renqiu Jingmei Rubber & Plastic Products Co., Ltd., China) and Aqualene™ (Olympus corporation, USA) elastomer were used for development of phantoms with known acoustic properties.

The Fig. 1. shows the drawing of front panel of the phantoms. Four inclusions with different diameters were manufactured - 5 mm, 7 mm, 9 mm and 13 mm.

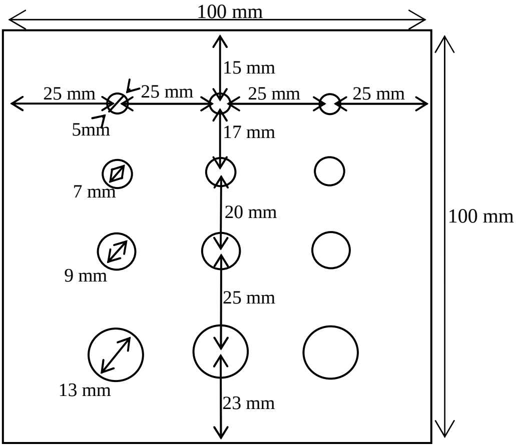
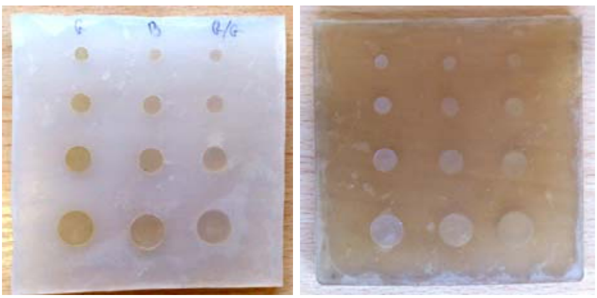


Fig. 1. Drawing of the front panel of the phantoms

The base of the first phantom (see Fig. 2 a) was two plates of silicone (thickness of each layer - 3 mm, silicone density – 1.3 g/cm^3) glued with sanitary silicone (thickness of the glue layer about 0,3 mm, glue density - 0.97 g/cm^3 at 20^{o}C). Aqualene™ low-attenuation elastomer (2.3 mm thickness, density 0.97 g/cm^3) glued with 1 mm silicone was used for mimicking of inclusions. The drawing of axial cross-section of the first phantom is presented in Fig. 3 a.

The second phantom was manufactured using the base of Aqualene™ low-attenuation elastomer (see Fig. 2 b). Ultrasonic properties of elastomer provided by manufacturers are close to properties of water: ultrasound velocity is 1540 m/s, attenuation 0.28 dB/mm at 5 MHz, characteristic impedance 1.463 MRayls [7]. Three plates of elastomer were glued together during manufacturing the base of the second phantom (thickness of each layer was 2.3 mm). Inclusions were made using 2 mm thickness silicone plates (see Fig. 3 b).



a b

Fig. 2. Top view of the phantoms: a) silicone phantom; b) elastomer phantom

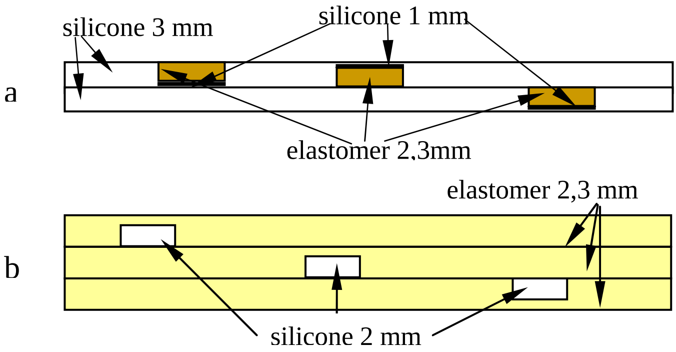


Fig. 3. The drawings of axial cross-sections of: a) silicone phantom; b) elastomer phantom

A high-frequency ultrasound scanner operating at a central frequency of 18.5 MHz (Dasel sistemas, Spain) with linear array probe (Imasonic, France) was used for ultrasonic investigation of the phantoms. The properties of the linear array are presented in Table 1.

Table 1. Parameters of the linear array

Central frequency (-6 dB)	18,5 MHz
Bandwidth (-6 dB)	65 %
Pulse duration	152 ns
Number of elements	128
Elementary pitch	0.25 mm
Total active length	31.95 mm
Number of elements in active aperture	16
Length of the active aperture	3.95 mm

Three silicone plates with different thicknesses (1 mm, 2 mm and 3 mm) and elastomer plate (2.3 mm thickness) were used for estimation of ultrasound velocity. The average of 20 A-scans ensemble acquired from different spatial positions was used for the measurements of ultrasound velocity and thicknesses of inclusions in the phantoms. The locations of boundaries of the plate surface and the plate bottom or inclusions between the surface and the bottom were evaluated applying amplitude threshold (threshold - 20% of absolute amplitude maximum).

Results. Primarily ultrasound velocities in the silicone and elastomer materials were estimated. The speed of sound was determined by measuring the time duration between the echoes reflected from the surface and the bottom of the base material sheet. Estimated ultrasound velocity in silicone material was 977.7 m/s ± 16.5 m/s (ultrasound velocity (mean ± SD), in 1 mm silicone plate – 979.0 m/s ± 23.7 m/s, in 2 mm silicone plate – 958.9 m/s ± 7.5 m/s, in 3 mm silicone plate – 991.6 m/s ± 3.3 m/s). Ultrasound velocity in elastomer material was 1536.7 m/s ± 17.4 m/s.

During the experiments scanning of the both manufactured phantoms was performed and the thicknesses of the inclusions were estimated. Filtered A-scan signals and B-scan images of phantoms are shown in Fig. 4.

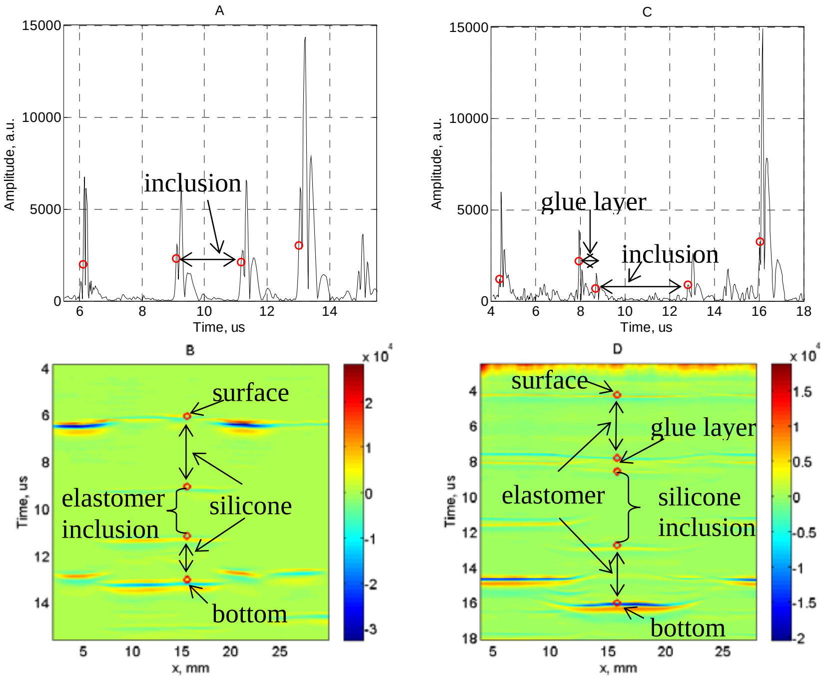


Fig. 4. A) An example of acquired A-scan signal (modulus) in silicon based phantom and in elastomer based phantom (C) at x = 16 mm; B) B-scan of the silicone based phantom and elastomer based phantom (D); The circles placed on A-scans and B-scans denote the detected boundaries of the phantoms.

The measured thickness of the inclusion in first phantom was 2.44 mm ± 0.02 mm and in the second – 2.05 mm ± 0.03 mm.

Conclusions. Two superficial human tissue mimicking phantoms with inclusions located at different depths were developed. In order to declare that these phantoms are suitable for the superficial tissue mimicking, we verified the phantoms with an ultrasonography tool. The investigation showed that the estimated ultrasound velocity of phantoms materials is close to the values provided by manufacturers and to the superficial tissue as well. Also, the estimated thicknesses of the inclusions are close to the real thicknesses of individual layers.

The irregular layer of the glue could be a factor for accuracy of measurements in this study. This is remarkable for the second phantom.

Our long-term superficial tissue-mimicking phantoms have a potential to be the promising tools for preclinical ultrasonic investigations of the superficial tissue lesions. These phantoms will be used in development and evaluation of the measurement methods and image processing algorithms in further studies with the aim to perform the early stage diagnosis of the diabetic foot ulceration signs and further evaluation.

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Ultrasound systems in dermatology are used for the assessment of tumoral and inflammatory processes; also it can become a promising technique for detecting early sings of diabetic foot ulceration. Biological phantoms are used for the development of imaging systems and evaluation of image processing algorithms. So, the purpose of this study was to develop the stable superficial tissue mimicking phantoms with inclusions located at different depths.
The investigation showed that the estimated ultrasound velocity of phantoms materials (in silicone material 977.7±16.5 m/s, and in elastomer – 1536.7±17.4 m/s) are close to the values provided by manufacturers and to the tissue as well. Also, the estimated thicknesses of the inclusions (in the first phantom – 2.44±0.02 mm, and in the second - 2.05±0.03 mm) are close to the real thicknesses of individual layers. Our long-term superficial tissue-mimicking phantoms have a potential to be the promising tools for preclinical ultrasonic investigations of the superficial tissue lesions.