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A novel agar-based phantom for quality control of medical ultrasound devices

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Abstract

Introduction: Regular quality control and verification of medical ultrasound systems are essential for maintaining high diagnostic accuracy. However, the high cost of commercial phantoms often limits their use, particularly in smaller healthcare facilities. This study aimed to develop a low-cost agar-based phantom and evaluate its suitability for ultrasound quality control.

Material and methods: The phantom was constructed using a plexiglass container filled with a 30 g/L agar solution. Test structures of different sizes were incorporated using nylon threads, small wooden pieces, and agar mixed with graphite. Measurements were performed with Voluson 730 Expert and GE Healthcare LOGIQ α 100 systems.

Results: Quality control tests included assessments of image uniformity, contrast resolution, spatial resolution, dead zone, maximum penetration depth, and geometric accuracy. The presence of targets of varying sizes enabled evaluations consistent with international quality assurance guidelines.

During testing, several image artifacts and minor malfunctions were observed, likely resulting from trapped air bubbles or transducer imperfections, which could influence image interpretation. Nevertheless, the results indicate that the developed phantom performs reliably for key ultrasound quality control procedures.

Conclusions: Its simple design, inexpensive materials, and adaptability make it particularly suitable for routine checks and training applications. Furthermore, its easy reproducibility allows customization for different clinical needs and equipment types. Overall, this study demonstrates that an agar-based phantom can serve as an effective, low-cost alternative to commercial models, supporting systematic quality control in ultrasound imaging. Such accessible solutions may help standardize testing procedures, enhance diagnostic consistency, and ultimately improve patient safety.

Keywords: USG; phantom; quality control

Introduction

In medical ultrasound devices all components must work properly. Regular quality control of medical ultrasound devices plays a crucial role in ensuring the highest diagnostic quality. Studies show that among others, using defective transducers can be the cause of misdiagnosis[1]. The aim of performing quality control is to enable early detection of equipment malfunctions and effective management of diagnostic devices[1,4-5]. The most frequently performed tests should be mechanical inspection and image uniformity[5].

International organizations such as the American Association of Physicists in Medicine (AAPM), the European Federation of Societies for Ultrasound in Medicine and Biology (EFSUMB) and the American Institute of Ultrasound in Medicine (AIUM) have provided guidelines for the quality control of the ultrasound transducers and the ultrasound machines themselves[6-8].

A comprehensive quality control program allows the ability to compare various ultrasound machines, transducers and other equipment when selecting new sonograph. It also enables verification of the manufacturer specifications with the actual state of the purchased equipment. These guidelines also refer to the need for performance tests after maintenance work or the introduction of new modules, as well as routine evaluation of consistency and efficiency. It is to ensure a minimum standard of diagnostic quality. The tests are performed using specialized phantoms that simulate the properties of human tissues and enable precise calibration and assessment of device performance[4-9].

Commercial phantoms for ultrasound are often too expensive, which can be a barrier to perform such tests[2]. Due to

Authors' contribution: A – Research concept and design, B – Collection and/or assembly of data, C – Data analysis and interpretation, D – Writing the article, E – Critical revision of the article, F – Final approval of the article.

the frequent lack of regular quality control tests, it is often impossible to evaluate if the device performs consistently and efficiently[5].

Recently, many studies have been published on developed ultrasound phantoms used for both educational and research purposes[10-12], with the use of gelatin, agar and polyvinyl alcohol (PVA) being the most frequently used materials[13]. The aim of this study was to create an agar-based phantom and assess its suitability for quality control of medical ultrasound devices.

Material and methods

The phantom was prepared using low-cost and readily available materials (**Figure 1**), drawing on technical information (e.g., structure types and arrangement) available for commercial phantoms[14]. It consisted of polymethyl methacrylate (PMMA) housing, a medium of an agar solution and test structures of various sizes, which were made of nylon thread, small pieces of wood and agar of different concentrations than the medium with the addition of graphite. The dimensions of the front and back walls of the housing were set at 200 mm in height and 180 mm in width, while the phantom's depth was 50 mm, matching the connector nut length.

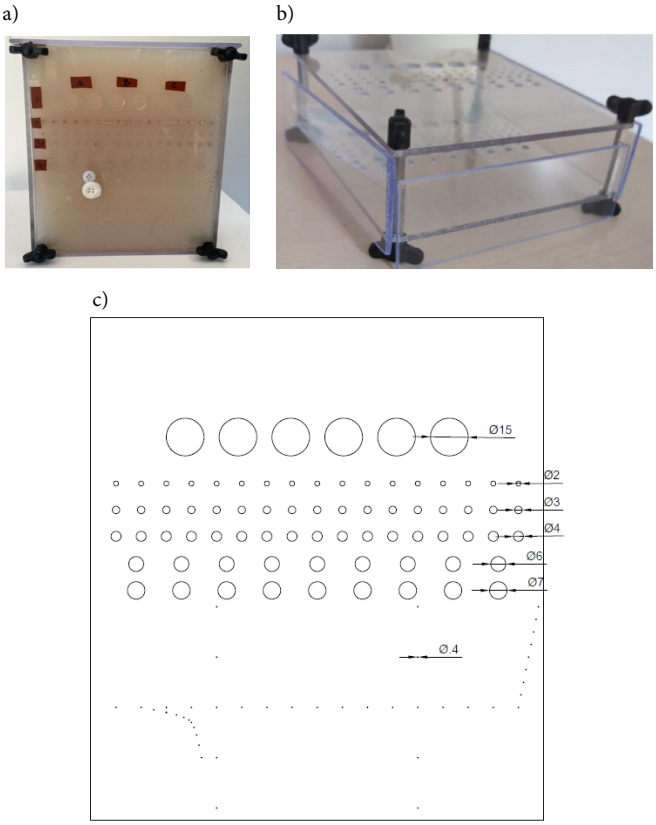

Figure 1. USG phantom: a) with agar filling, b) without agar filling, c) diagram.

The phantom design included targets of various sizes arranged across different zones. The target areas were prepared in seven diameters and filled with different materials. The section for contrast and grayscale measurement consisted of six targets with a diameter of 15 mm. Targets with five different diameters, filled both with small wooden dowels and agar with graphite (**Table 1**) were used for geometric measurement accuracy. The smallest target holes, with diameter of 0.4 mm, were filled with nylon thread target of 0.16 mm in diameter. The diameter of the measured thread is smaller than that of the hole. A larger hole diameter allows the use of threads with different, larger or smaller, diameters, which makes it possible to adapt the phantom to various measurement needs. A structure of 17 such points, spaced 10 mm apart in a straight line, was used to measure the depth of maximum penetration. An additional eight targets, prepared in the same manner (nylon thread 0.16mm diameter) and positioned near the scanning surface at 5 mm intervals, were used to characterize the dead zone. Another set of eight targets (nylon thread 0.16mm diameter), arranged perpendicularly to the line of 17 points, served for near- and far-range resolution measures. The last section consisted of an arc composed of 11 targets, designed for axial and lateral resolution assessment. The numbers of targets of each size, along with the filling materials used, are given in **Table 1**.

The selection of the medium for filling the phantom was preceded by a literature review[13] and supported by our own experience in this field. One of the main objectives was to choose a readily available material. To refine the selection, the mechanical properties of samples prepared with different agar concentrations were assessed.

The prepared samples were analyzed using an OPBOX 2.0 device (produced by Optel), including measurement of ultrasonic wave propagation velocity. The average measured velocity was 1537 m/s, which is consistent with values reported in the literature[13].

Table 1. Sizes, materials and purposes of each target area.

Diameter [mm]	Number of targets	Filling material	Purpose
15	6	Agar, water, graphite	Grayscale, Contrast resolution
7	9	Agar, water, graphite	Geometric measurement accuracy
6	9	Agar,water, graphite	Geometric measurement accuracy
4	17	Agar, water, graphite	Geometric measurement accuracy
3	17	Agar, water, graphite	Geometric measurement accuracy
2	17	Wooden dowels	Geometric measurement accuracy
0.4	44	Nylon thread (0.16 mm)	Depth of maximum penetration, Close-range and far-range resolution, Dead zone, Axial and lateral resolution

Additionally, the influence of the phantom filling method on the final result was examined. For this purpose, the samples were prepared in two variants: poured as a single layer and as multiple layers. A total of eight samples with varying agar concentrations were prepared using a standardized procedure. Each sample was prepared using 200 ml of boiling water. Agar was added ranging from 5 g/L to 30 g/L. The solution was continuously stirred until the agar dissolved.

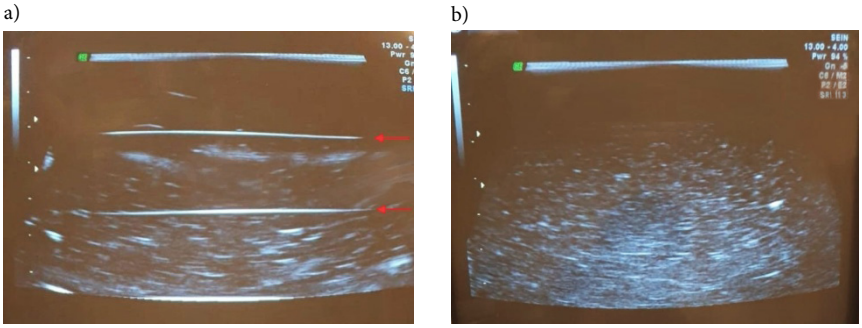

Figure 2. Image of a sample: a) homogeneous, b) with visible layering.

A portion of the water evaporates during heating, that is why the total solution volume was carefully monitored throughout the process to avoid significant differences in concentration. The uncertainty of mass measurement due to limitations of the measuring devices was 0.01 g and the uncertainty of volume measurement was 10 ml.

The final solution was transferred into designated sample containers and was stored at a temperature of 4°C for further analysis.

Results

The measurements were carried out using two different ultrasound machines: Voluson 730 Expert and GE Healthcare LOGIQ α 100.

Due to the mechanical properties, an agar solution at a concentration of 30 g/L was selected as the medium. Ultrasound imaging revealed that pouring the medium in layers introduces artifacts into the image. Therefore, it should be poured in a single step (**Figures 2a** and **2b**).

In the next step series of measurements were conducted on ultrasound machines using various types of transducers: sector, linear, and convex at different frequencies. Tests were performed under conditions simulating typical clinical settings, with a constant room temperature matching a standard patient examination room. This approach allowed for the acquisition of results that closely reflect actual equipment usage.

The tests included assessments of image uniformity, contrast, spatial resolution, dead zone measurement, penetration depth, and geometric accuracy.

During the evaluation of uniformity, attention was paid to the presence of artifacts, changes in brightness near the edges, brightness variations between focal zones or the presence of faulty pixels. Areas of uniformity were identified, clearly visible with regular, grainy noise (**Figure 3a**). In some regions there were horizontal streaks and other artifacts present, caused by trapped air resulting in reflections and shadows that distorted the image. While imaging the phantom using the GE Healthcare LOGIQ α 100 device, black spots were observed on the image, marked with red arrows. They were caused by piezoelectric elements in the transducer that weren't function-

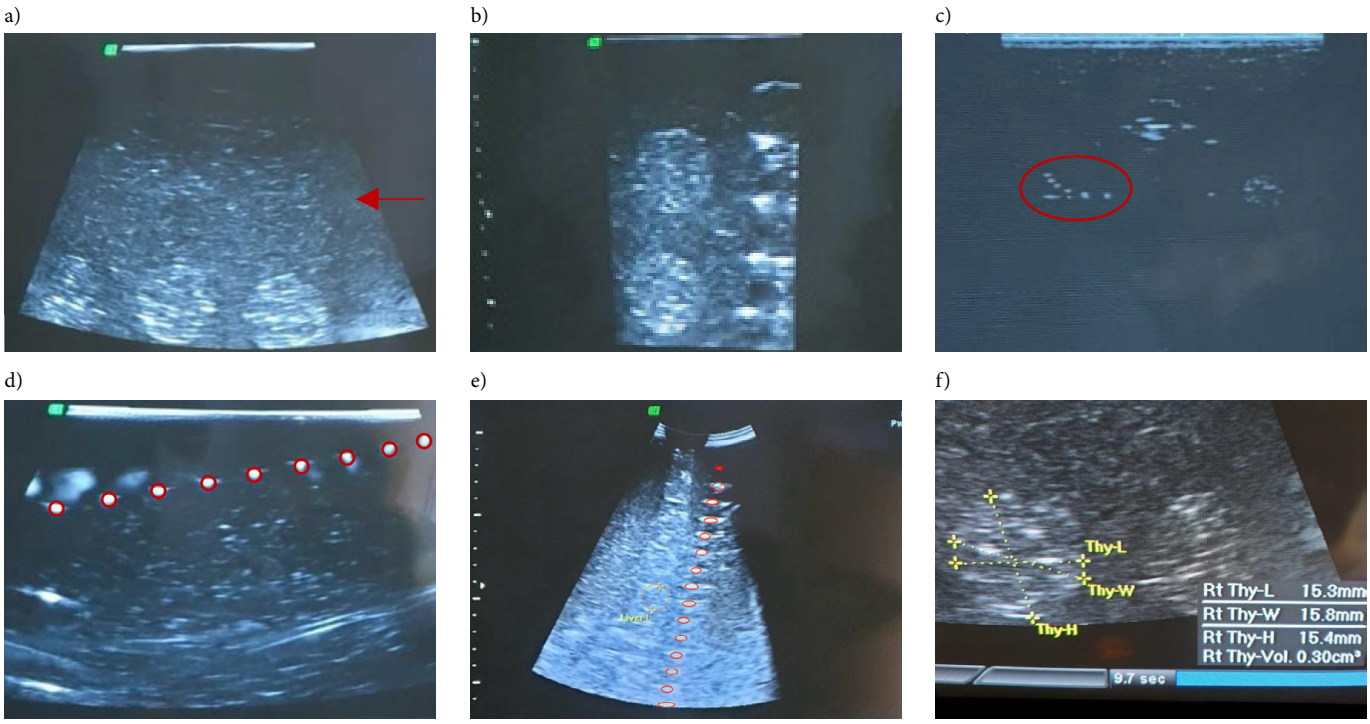

Figure 3. Voluson 730 Expert, convex transducer. Tests: a) uniformity, b) contrast, c) spatial resolution, d) dead zone measurement, e) penetration depth, f) geometric accuracy.

ing well. It did not meet the requirements for clinical examinations (**Figure 4**).

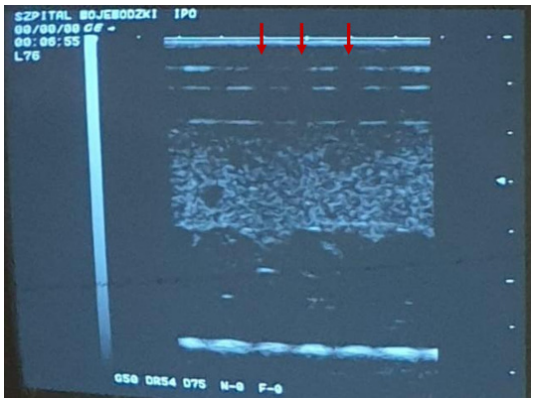

Figure 4. GE Healthcare LOGIQ α 100, linear transducer. A partially homogeneous area with grainy noise; artifacts in the form of black spots.

Contrast resolution evaluation (**Figure 3b**) involved a qualitative assessment of the smallest difference in grayscale detectable by the human eye on the image. The targets appeared uniform, with a clearly defined boundary between the target and the surrounding medium.

The spatial resolution tests focused on the system's ability to distinguish two adjacent objects under high-contrast conditions. Axial resolution is typically worse than lateral resolution due to physical phenomena. A 90° arc zone was imaged and marked on the image (**Figure 3c**). The targets were placed at progressively smaller, known distances. Better resolution was observed for parallel to the direction of wave propagation targets than for positioned perpendicularly.

The dead zone is a result of limitations in ultrasound equipment. Changes in the size of the dead zone under constant imaging parameters may indicate variations in transducer performance. The measurements aimed to determine the size of the dead zone using the phantom. However, reflections in phantoms may differ from those in patients due to differences in acoustic impedance between human skin and the phantom material. But even targets located at a depth of 2 mm were successfully visualized (**Figure 3d**).

For the assessment of maximum penetration depth, the maximum distance at which the targets are visible was determined. A decrease in the maximum penetration depth at constant imaging parameters may suggest a decline in transducer performance. A maximum of 15 target points were visible, corresponding to a depth of 165 mm (**Figure 3e**). The depth targets were distinguishable, although those positioned deeper exhibited more artifacts due to stronger reflection and scattering effects.

A geometric accuracy assessment was conducted to verify if the sizes of the target areas were displayed as expected. It was also tested if the distances between them were measured accurately. Measurements were performed for both near and far distances from the phantom surface. The obtained results were close to the actual values (**Figure 3f**).

Discussion

In this study an agar-based phantom was created. The use of different sized target areas and defined zones enabled tests to be performed in accordance with guidelines of international institutions. During quality control, artifacts were observed in the phantom, which could potentially affect the interpretation of the images. Future improvements should consider optimizing the medium preparation procedure to minimize the risk of air bubbles, which are likely sources of artifacts. However, the phantom was sufficient to detect malfunctioning piezoelectric elements in one of the transducers used with the GE Healthcare LOGIQ α 100 device. These findings in uniformity test confirm that the developed phantom is an effective tool for ultrasound diagnostic performance testing.

Quality control with a phantom can not only verify the findings observed during the patient examination but also has a potential in finding malfunctions before it is noticed. Therefore, it is recommended to be performed regularly. One of the problems is the availability of affordable phantoms. The low production cost, based on using inexpensive materials and simple construction of the developed phantom make it accessible for medical facilities to perform recommended tests of medical ultrasound devices. The proposed phantom allows the implementation of regular quality control procedures, improving the quality of ultrasound imaging and diagnostic accuracy.

The custom-designed phantom offers flexibility for future adaptations. One important topic for further research would be to develop test structures that meet the specific requirements of different equipment or clinical applications. Another interesting topic would be how to extend phantom longevity. Although the agar-based medium had a suitable mechanical properties comparable to biological tissue, it showed a tendency to develop mold and dry out during storage. This significantly limits its long-term usability. To slow down the degradation over time we can use preservatives. Based on its cost and availability, sodium benzoate and glycerin could be a potential solution. However, their use requires further investigation and validation.

Conclusion

The designed phantom was used to perform tests recommended by international organizations and referenced in scientific literature. The phantom was tested using a Voluson 730 Expert ultrasound system and a GE Healthcare LOGIQ α 100 system.

Based on the analysis of the obtained images, the constructed phantom has shown potential as a tool for quality control of medical ultrasound devices. This represents an important contribution to improving the quality of medical imaging and patient safety.

The implementation of the presented project could promote routine quality control testing. In addition to its low cost and ease of production, the phantom offers the advantage of being easily adaptable in terms of test structure.

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