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Development of a Color Doppler Phantom Based on SimuGel Gelatin as an Innovative Simulation Medium for Laboratory Practicum in the Ultrasonography Course

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Doppler Phantom, Simugel Gelatin, Ultrasonography Simulation.

Abstract

Ultrasonography, particularly Doppler ultrasound, requires adequate practical skills to ensure accurate examination and interpretation of blood flow characteristics. However, student training is often limited by restricted patient availability, safety considerations, and insufficient opportunities for repeated practice. Simulation media, such as phantoms, provide a controlled and safe learning environment; however, commercial Doppler phantoms remain relatively expensive and less accessible for educational institutions. This study aimed to develop a SimuGel gelatin-based Color Doppler phantom as an innovative simulation medium for laboratory practice in ultrasonography courses. This study employed a Research and Development (R&D) method using the ADDIE (Analysis, Design, Development, Implementation, and Evaluation) model. The phantom was developed using SimuGel gelatin, glycerin, distilled water, psyllium husk, preservatives, acrylic components, and an aquarium pump-based flow system. Product feasibility was evaluated by three experts, while practicality testing involved 30 students. Data were collected through observation, questionnaires, interviews, and product trials, then analyzed descriptively using a Likert scale. The results showed that expert validation categorized the phantom as feasible, with assessment scores ranging from 2.67 to 4.00. Student evaluations indicated a very feasible category, with an average score of 3.70. The phantom successfully generated Color Doppler visualization, supported training in Doppler ultrasound parameters, and improved students' understanding of ultrasound examination procedures. However, the continuous flow system limited the simulation of physiological pulsatile blood flow characteristics. In conclusion, the SimuGel-based Color Doppler phantom was a feasible, practical, and affordable learning medium for Doppler ultrasound education, although further improvements are required to enhance the realism of the simulated blood flow.

INTRODUCTION

Ultrasound is an imaging technique that uses high-frequency sound waves, typically ranging from 2 to 15 MHz, to produce anatomical images. The ultrasound modality is also one of the most widely available imaging modalities in healthcare facilities because it is considered safe, relatively inexpensive, non-invasive, and does not involve ionizing radiation (Avola et al., 2021; Poggi & Palavecino, 2024).

One of the technologies within the ultrasound modality that is commonly used to support diagnostic evaluation is Doppler ultrasonography (Abramowicz, 2021; Dietrich et al., 2022). The Doppler effect was first introduced by Austrian physicist Christian Doppler in 1842. The Doppler effect describes the change in frequency that occurs when sound waves are reflected from a moving object (Grogan & Mount, 2025). This phenomenon serves as the fundamental principle of Doppler ultrasound. Doppler ultrasound is an ultrasound-based imaging technique used to detect and measure blood flow within blood vessels (Okpatrioka, 2023; Wasickanin et al., 2020). This technique plays an important role in diagnosing vascular disorders, such as thrombosis, stenosis, venous insufficiency, and other pathological conditions associated with the circulatory system (Meola et al., 2021; Russ et al., 2023).

Mastering the Doppler ultrasound technique requires complex skills, including technical aspects such as transducer orientation and optimization of various Doppler parameters, including color box size, color scale, color gain, wall filter, and angle steering, as well as the interpretation of spectral and color Doppler findings. The accuracy of diagnostic information obtained from ultrasound examinations depends largely on the examiner's competency. Therefore, achieving optimal understanding and performance in Doppler ultrasound examinations requires standardized scanning skills developed through appropriate training and clinical experience (Henríquez-Camacho et al., 2021; Meola et al., 2021).

The process of learning Doppler ultrasound skills in educational institutions often faces several challenges. Limited patient availability, patient safety considerations, and restricted practice time are major obstacles to providing optimal learning experiences for students. Under these conditions, the use of simulation media, such as phantoms, represents a strategic approach to supporting the learning process. Simulation media allow students to perform repeated practice without risk to patients while providing a controlled learning environment that can be adjusted according to competency levels (Giannotti et al., 2022; Jagoda et al., 2023; Schmidt et al., 2021).

Gelatin is one of the materials widely used in phantom development because it has acoustic properties similar to human tissue, with a sound propagation speed ranging from approximately 1,518 to 1,535 m/s, making it effective as a simulation medium for ultrasound practice. However, gelatin has limitations, particularly in terms of durability. It is susceptible to dehydration, mechanical degradation, and microbial growth when stored at room temperature without appropriate preservatives (Abraham et al., 2022; Kim et al., 2023; Shrimal et al., 2024).

Various phantom models have been developed for medical training, including phantoms for intravenous catheterization, lumbar puncture, abscess drainage, needle aspiration, prostate imaging, breast tissue examination, and thyroid procedures. However, most commercially available ultrasound phantoms remain relatively expensive and have limited accessibility, particularly in educational institutions with constrained resources (Phillips et al., 2023; Selame et al., 2020).

SimuGel™ was selected as an alternative to conventional gelatin for phantom development due to the need for a more stable, reproducible, and durable material for ultrasound simulation. SimuGel™ demonstrates thermal reversibility, allowing repeated melting and remolding processes without significant chemical degradation. This characteristic helps maintain consistency in elasticity and material performance across multiple use cycles while improving cost efficiency and sustainability in educational and research laboratory settings.

The development of a SimuGel-based Color Doppler phantom has the potential to significantly contribute to improving the effectiveness of practical skill training. Students can actively explore scanning techniques, understand the influence of Doppler angles, and develop analytical skills in interpreting spectral and color Doppler results. Furthermore, the development of gelatin-based phantoms creates opportunities for interdisciplinary collaboration among medical education, biomedical engineering, and materials science. Such collaboration is essential for designing educational tools that are not only functional but also scientifically grounded and reproducible in institutions with limited resources.

This research focused on designing, developing, and testing a simple Doppler phantom based on SimuGel™ that could be used as a simulation medium for ultrasound practical training, particularly for students in the Radiodiagnostic and Radiotherapy Engineering Study Program.

Based on the need to improve competency in Doppler ultrasound practice, address limitations in available training media, and promote innovation in sonography education, this study was conducted under the title "Development of a Color Doppler Phantom Based on SimuGel Gelatin as an Innovative Simulation Medium for Laboratory Practicum in the Ultrasonography Course."

This research aimed to develop a SimuGel gelatin-based Color Doppler phantom as an innovative, affordable, and applicable ultrasound learning simulation medium to support Doppler ultrasound training. The research focused on the design and fabrication process of the phantom, feasibility evaluation by experts, and assessment of its practicality in educational settings. The objectives included developing the phantom model, evaluating product quality and functionality through expert assessment, and analyzing its practicality based on student responses. Theoretically, this research is expected to contribute to the advancement of ultrasound simulation media development. Practically, it may provide an alternative training medium for health education institutions, improve students’ understanding and skills in Doppler ultrasound examinations, and serve as a reference for future studies developing more effective and realistic ultrasound simulation tools.

METHOD

This research employed the Research and Development (R&D) method using the ADDIE model, which consists of the Analyze, Design, Develop, Implement, and Evaluate stages. This method was selected to develop a SimuGel gelatin-based Color Doppler phantom as a simulation medium for ultrasound learning. During the analysis stage, interviews with ultrasound course lecturers and literature reviews were conducted to identify learning needs and determine the required phantom specifications. The collected information was used as the basis for product design and development.

During the design and development stages, the Color Doppler phantom was fabricated using SimuGel™ gelatin, glycerin, distilled water, psyllium husk, and preservatives. The phantom was placed in an acrylic container equipped with two flow channels and an aquarium pump to simulate blood flow that could be visualized using Color Doppler and Spectral Doppler modes. After fabrication, initial testing was conducted to evaluate the functionality of the flow system, image quality, and suitability of the phantom as a learning medium for ultrasound practice.

The implementation stage involved 30 students from the D4 Imaging Technology program at several health education institutions. Data were collected through observations, interviews, product trials, and questionnaires administered to experts and students. The research instrument demonstrated acceptable validity, with the r-count values exceeding the r-table value (0.3610), and showed high reliability with a Cronbach's Alpha value of 0.925. The collected data were analyzed using descriptive quantitative analysis based on mean scores from the Likert scale to evaluate the feasibility and practicality of the phantom as an ultrasound learning medium.

RESULTS AND DISCUSSION

Product Manufacturing Process

A product in the form of a Gelatin-based Phantom Doppler has been made which will be used as an innovative simulation medium in the Doppler ultrasound learning process. The phantom creation was carried out in December 2025 – January 2026. The manufacturing process is carried out by melting the gelatin base material and printing into the acrylic that has been designed, then making Blood Mimicking Material.

1. Phantom Gelatin

The steps to make phantom gelatin as the main structure are as follows:

a. The first step is to prepare an acrylic container with a size of 12 x 10 x 9 cm
b. Preheat the oven as a first step before the Simugel is melted at a temperature of 150 degrees and a time setting of 10 minutes.
c. Prepare a heatproof container, and place the Simugel gelatin in the preheated Oven.
d. Set the oven to 150 degrees for 30 minutes to melt the simugel.
e. Print Simugel into a pre-designed acrylic mold.

2. Blood Mimicking Material

The Blood Mimicking Material used in this study was formulated to resemble the characteristics of blood flow in humans, especially in the context of Doppler ultrasound imaging. The BMM is prepared by paying attention to the main parameters in the form of viscosity, flow homogeneity, and the ability to produce stable and consistent Doppler signals when flowed through the hose on the phantom. The stages of making BMM are as follows:

a. Prepare acrylic that has been designed with a size of 8 cm x 8 cm x 8 cm. With 2 holes as inflow and outflow flow system
b. Mix 1 Liter of Aquades with 1 gram of Psyllium Husk. Psyllium Husk is used as a particle enhancer that functions as a scaterrer.
c. Add Glycerin to the Aquades solution. Glycerin is used as a viscosity enhancer of liquids.
d. Add Methylparaben as a preservative

Phantom Doppler Initial Test Stage

1. Tools and Materials

The tools and materials used to test the phantom are focused on the ultrasound device and the type of probe used. The ultrasound device used by the GE Healthcare brand Type Logiq P10 is equipped with Color Flow and Pulsed Wave modes. The probes used are Linear probes of the L3-12-RS type with a frequency range of 2 – 11 MHz, and a footprint area of 51.2 mm. This type of probe is selected based on the frequency that is most suitable for the simulation of superficial vascular structures, so that it is able to optimally represent the conditions of the Doppler examination. The tools and materials used are listed in figure 4.7 below.

Figure 1. GE Logiq P10 Tool with L3-12 Type Linear Probe

2. Phantom Preparation
   a. Prepare 2 electric switches to install the aquarium pump electricity
   b. Position the phantom in the position as shown in Figure 4.8 below.

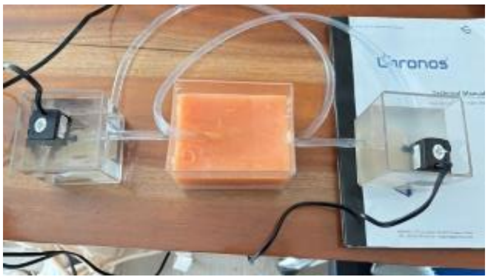

Figure 2. Ghost Color Doppler

3. Tahap Scanning

The next stage is to ensure that the viscosity of the liquid is in accordance with good color Doppler visualization. In the 1st experiment, the viscosity of the liquid was not good because the fluid flow appeared to be less stable to the change in parameters, so the color Doppler signal produced was not homogeneous and it was difficult to represent the blood flow pattern physiologically as shown in Figure 4.9. Therefore, in the next stage, the composition of the liquid material is adjusted to increase viscosity by adding glycerin and psyllium husk, with the aim of obtaining flow characteristics that are more blood-like and producing a clearer, stable, and consistent color Doppler visualization as seen in figure 4.10. The ready-to-use formulation of BMM liquid is placed in an acrylic container as shown in figure 4.6.

1st attempt

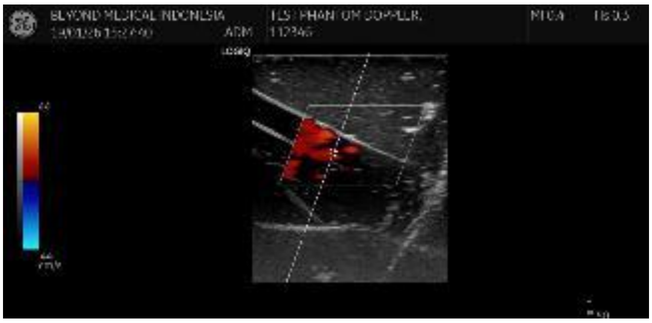

Figure 3. Results of the 1st experiment with 100 ml of Glycerin, 0.5 grams of Psyllium Husk and 1 liter of Aquades

2nd attempt

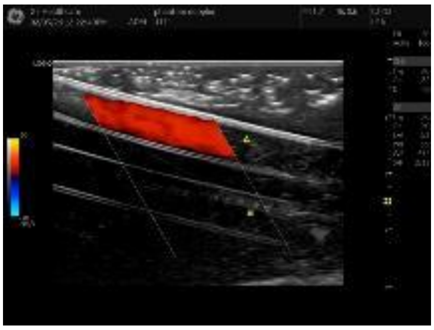

Figure 4. Results of the 2nd Experiment with Glycerin 200 ml, Psyllium Husk 1 gram and Aquades 1 liter

a. The results of longitudinal piece phantom doppler imaging without Color mode. It appears that 2 hoses (A and B) are arranged in parallel
b. The results of the Longitudinal cut phantom doppler image with Color mode. It appears that 2 hoses (A and B) are parallel to each other. The color mode on the blood vessel A appears as a red color indicating that the flow is flowing close to the probe marker.

Phantom Doppler Test Stages by Experts

1. Phantom Doppler Testing Levels by Experts

The product trial will be carried out in December 2025 in 3 different places according to each respondent. The phantom test was also carried out with 3 ultrasound instruments of different types so that it could be seen to the stability of the quality of the resulting image. The trial by respondent A was carried out at the PUSKI Jakarta Building using the GE Logiq P8 ultrasound device with the ML6-15 Linear probe type. The trial by respondent B was carried out at East Bekasi Hospital using a GE Logiq P7 ultrasound device with a Linear L3-12 probe type. The trial by respondent C was carried out at PT Beyond Medical using a GE Logiq P10 ultrasound device with a Linear L3-12 probe type.

After conducting a trial on the design of the Doppler phantom, respondents were obtained from experts who assessed the feasibility of the phantom as a simulation medium for ultrasound learning. The assessment was carried out through an expert validation process using a questionnaire instrument that covered several aspects, including the suitability of the phantom design, the similarity of the characteristics of the Doppler flow to biological conditions, the quality of the visualization of the Doppler signal, and the stability and ease of use of the phantom during the examination process. Experts conduct live testing using Doppler mode on ultrasound machines, then provide scores and inputs based on their respective clinical and academic experiences. The results of the expert validation are then analyzed descriptively to determine the level of suitability and feasibility of the developed Doppler phanthoma, and used as a basis for refining the design before it is applied to the student learning stage. There are average test results from the questionnaire that are assessed by experts as shown in table 1.

Table 1. Descriptive Statistical Test Results of Expert Assessment

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
P1	3	3	4	3.67	.577
P2	3	4	4	4.00	.000
P3	3	2	3	2.67	.577
P4	3	3	4	3.33	.577
P5	3	3	4	3.33	.577
P6	3	4	4	4.00	.000
P7	3	2	3	2.67	.577
P8	3	2	3	2.67	.577
P9	3	2	4	3.00	1.000
P10	3	3	4	3.67	.577
P11	3	3	3	3.00	.000
P12	3	4	4	4.00	.000
P13	3	2	4	3.00	1.000
P14	3	3	4	3.33	.577
P15	3	3	4	3.33	.577
P16	3	2	4	3.00	1.000
P17	3	4	4	4.00	.000
P18	3	4	4	4.00	.000
P19	3	4	4	4.00	.000
P20	3	3	4	3.67	.577
Valid N (listwise)	3				

The results of the descriptive statistical analysis showed that the assessment given by three experts (N = 3) on 20 indicators (P1–P20) on the developed Doppler phantom was in the good to very good category. In general, the mean value ranges from 2.67 to 4.00 on a rating scale of 1–4. The highest average score of 4.00 was found in several indicators such as P2, P6, P12, P17, P18, and P19, which indicates that all experts gave very good or very appropriate assessments of these aspects. This indicates that the Doppler phantom indicator is considered to have met the criteria expected by experts.

Most of the other indicators have a mean value between 3.00–3.67, such as P1, P4, P5, P10, P11, P14, P15, P16, and P20, which indicates that the Doppler phantom is in the good category and is considered suitable for use as a simulation medium for Doppler ultrasound learning. Meanwhile, some indicators such as P3, P7, and P8 have a mean value of 2.67, which is the lowest average value in this assessment. However, the value is still in the category of good enough, so these aspects can still be used but require further improvement or development. Judging from the standard deviation value, some indicators have a value of 0.000, which means that all experts give the same assessment (there is no variation in assessment). In other indicators, the standard deviation ranged from 0.577 to 1,000, indicating a slight difference in perception between experts, but still within the limits of small variation.

Overall, the results of this descriptive statistical analysis show that the developed SimuGel-based gelatin Doppler phantom has a good feasibility level according to the assessment of experts, so that it can be used as an innovative simulation medium in learning Doppler ultrasound practices for students.

Phantom Doppler Practicality Test

The Doppler phantom practicality test was carried out to determine the level of ease of use and effectiveness of phantom as a simulation medium for ultrasound learning from the perspective of the user, namely students. This test involved 30 student respondents of the Radiodiagnostic Engineering and Radiotherapy Study Program who had participated in practicum activities using the developed phantom. The assessment was carried out after students simulated a Doppler examination directly using an ultrasound machine (Hoskins et al., 2019).

The practicality test instrument was prepared in the form of a questionnaire that contained statements related to the ease of phantom preparation, ease of operation during practicum, phantom stability during scanning, and visualization of the resulting Doppler signal. Students provide assessments based on their experience of using phantom during practicum activities. The data obtained were then analyzed descriptively to illustrate the level of practicality of the Doppler phanthoma. There are 20 questions that are assessed by students along with the results of statistical analysis contained in Figure 4.11 and Table 4.6.

Based on a descriptive analysis of 20 statements, the overall average score was in the range of 3.47–3.87 with an overall average of 3.70. Referring to the interpretation category (3.26–4.00 = Very Feasible), the respondents' assessment showed that gelatin-based Doppler phantom was considered "Very Feasible" to be used as a learning medium for ultrasound practice. The highest rated aspects were safety of use (mean 3.87) and comfort for repetitive exercise (mean 3.83), followed by increased confidence and effectiveness as pre-practice exercises in patients (mean 3.80 each). Meanwhile, several indicators related to the quality of Doppler observations and interpretation also remain in the Very Decent category, although they tend to be lower than the convenience and safety aspects, such as the ease of observing and interpreting the Doppler spectrum (mean 3.47) and the clarity of the Doppler angular effect (mean 3.57). In general, these findings confirm that phanthoms are not only easy to use and safe, but also help connect theory with practice as well as support the understanding of basic concepts and Doppler parameter regulation in learning.

After research and development (Research and Development) accompanied by product testing by various experts relevant to the research objectives, the discussion was focused on the results of validation by experts, as well as on the practicalities assessed by the respondents. Each finding was analyzed to assess the extent to which the developed Doppler phantom was able to optimally simulate blood flow on Doppler ultrasound examination, both in terms of color Doppler visualization and the suitability of the material characteristics used.

Image Quality Comparison

In the examination of carotid ultrasound in patients, the quality of Doppler images is influenced not only by the operator's ability to regulate machine parameters, but also by individual anatomical and physiological variations. Students will have difficulty distinguishing whether spectrum distortion, aliasing, or low diastolic resolution is caused by parameter setting errors or by the patient's pathological condition, As for the comparison of the Carotid Artery Ultrasound Images in patients and the phantom color doppler shown in Figure 3.

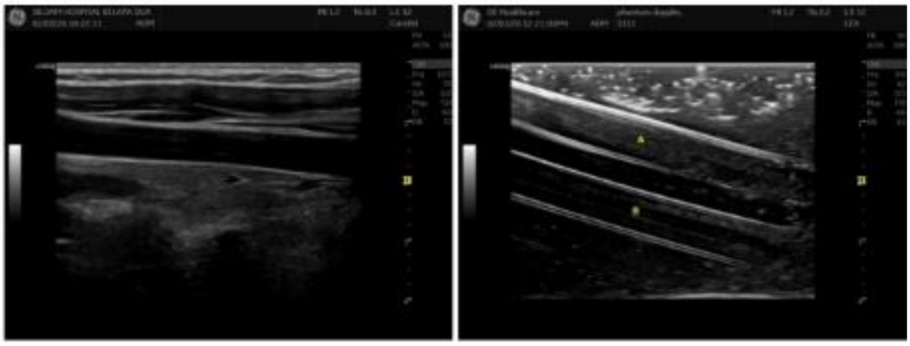

Figure 3. Results of Comparison of Carotid Ultrasound Images in Patients and with Phantom Color Doppler. Figure a) B-Mode Image of Carotid Artartery, Image b) B-Mode Image of Phantom Doppler

Arterial blood vessels have distinctive pulsatile characteristics according to the function and location of these vessels, one of which is in the carotid artery. The carotid artery in humans exhibits a pulsatile flow pattern with a high systolic component as well as a continuous diastolic flow, reflecting relatively low peripheral resistance to cerebral circulation. On the Pulsed Wave Doppler ultrasound examination, the flow spectrum in the carotid artery was characterized by high systolic peak (PSV) and lower diastolic flow, resulting in Pulsatility Index (PI) and Resistive Index (RI) values. In the phantom color doppler developed, the phantom flow system relies heavily on the flow speed generated by the aquarium pump. Aquarium pumps available on the market, tend to have the characteristics of stable and continuous flow speed, so they do not have a systolic peak as shown in Figure 4.

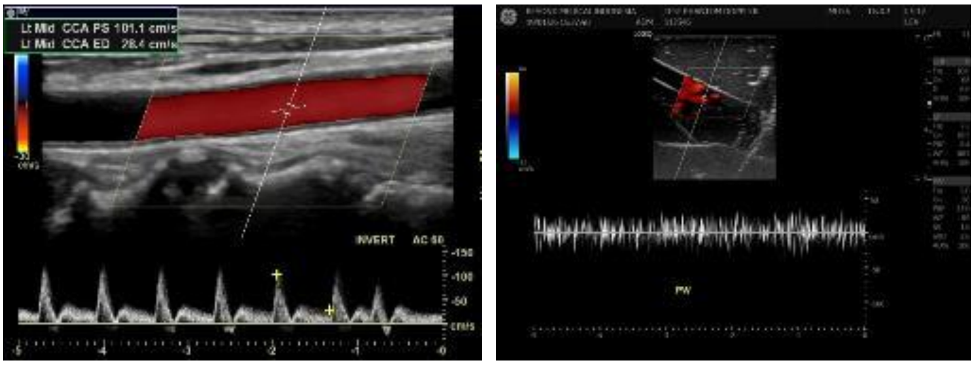

Figure 4. Comparison of flow characteristics in the Carotid and Phantom Doppler arteries. Figure a) Characteristics of pulsatile flow in the Carotid Artery, Figure b) Characteristics of continuous flow in the doppler phantom

Phantom Komersial

The commercial Phantom Doppler is a standardized simulation device designed to mimic the acoustic characteristics of biological tissues as well as the dynamics of human blood flow under controlled conditions, thus playing an important role in training, calibration, and quality assurance (QA) of ultrasound systems. One of the commercial phantom circulating in Indonesia is the brand of Sun Nuclear Doppler Flow Phantom 403 as shown in Figure 5.3, which was developed as a calibration tool in the testing of ultrasound instruments. Based on Sun Nuclear's product datasheet, the phantom uses HE (High Equivalency) Gel™ as a patented tissue-mimicking material, with acoustic characteristics that resemble human tissue and an attenuation response to high frequencies, allowing for clinically representative evaluation of axial resolution and penetration power.

In the hemodynamic aspect, the Sun Nuclear Doppler Flow Phantom 403 is equipped with a flow system that is able to produce both constant and pulsative flow, so that it can simulate physiological blood flow conditions, including laminar patterns with parabolic velocity distribution within the lumen of the vessels. The ability to produce controlled flow rate variations makes this phantom particularly relevant in testing Doppler parameters such as flow velocity, velocity measurement accuracy, as well as hemodynamic indices such as RI and PI.

The use of commercial phantom Doppler still faces some limitations, especially in terms of relatively high costs and limited accessibility in educational institutions, particularly in developing countries. Based on the INAPROC 2026 electronic catalog, the price of the Sun Nuclear phantom is IDR 413,861,369.00. This condition creates a research gap in the provision of simulation media that is more economical, easy to make, and flexible, but still able to represent adequate acoustic characteristics for training needs. Therefore, the development of gelatin-based Phantom Doppler, such as SimuGel, is a promising innovative alternative, as gelatin materials are relatively inexpensive, easy to obtain, and can be modified according to learning needs. In addition, gelatin-based phantom has the potential to be used repeatedly with a simple reproducible process, making it more efficient in supporting students' ultrasound practices in a sustainable manner without relying on expensive commercial devices. The details of the costs required to make 1 Simugel-based Phantom are found in the following Table 2.

Table 2. Phantom Crafting Cost

Yes	Item Name	Pricing
1.	Simugel	IDR 965,000
2.	3 Acrylic Pieces	IDR 125,000
3.	2 Pieces of Hose	IDR 20,000
4.	Glycerin	IDR 15,000
5.	Aquades	IDR 9,000
	Total	IDR 1,134,000

Design and Build a Phantom Product

Phantom Doppler is a simulation medium designed to mimic blood flow and characteristics of human blood vessels on Doppler ultrasound examinations, so that it can be used as a means of learning and training without involving real patients. Phantom Doppler allows users to understand the relationship between Doppler parameter settings such as color gain, pulse repetition frequency (PRF) or scale, and Doppler angle in a more controlled way.

Grice et al. (2016) stated that the Doppler phantom is useful as a tool for evaluating the performance and stability of Doppler ultrasound systems, both in the context of training and quality assurance. This phantom allows for consistent and repeatable flow simulations, allowing users to exercise their Doppler signal acquisition and interpretation capabilities objectively and minimize the variability that often occurs at patient examinations.

Doppler ultrasound practice learning in educational institutions generally utilizes probandus or limited simulation through theoretical exposition and demonstration from practice instructors. The use of probandus has limitations, including non-uniform anatomical variations, limitations on repetition of examinations, and ethical and human safety considerations. So that students have limited opportunities to practice setting Doppler parameters, such as adjusting gains, insonation angles, and optimizing blood flow visualization repeatedly and controlled.

1. Phantom Doppler Gelatin

Phantom gelatin in this study was made using the basic material of the Simugel brand medical based gelatin. The selection of SimuGel brand medical-based gelatin as the basic ingredient of phantom in this study was based on several technical and practical considerations. Compared to conventional gelatin, SimuGel has better physical stability, characterized by resistance to temperature changes, structural degradation, and the growth of microorganisms, so it does not require the addition of preservatives. In addition, SimuGel produces a more consistent texture, which plays an important role in producing stable B-mode and Doppler ultrasound images. In terms of practicality, SimuGel can be diluted and reprinted without experiencing a decrease in material quality, thus supporting the development and modification process of phantom repeatedly in the Research and Development approach.

The work stage is carried out by melting Simugel at a temperature of 150°C for 30 minutes. The simugel is melted and then printed into acrylic which is made with a size of 10 cm x 8 cm x 8 cm which has been measured according to the size of the linear probe footprint. Acrylic is equipped with 2 holes on each side with the height of the 1st hole from the left side 5 cm high from the top, the position of the 2nd hole is given a distance of 0.5 from the first hole. On the opposite side, the position of the 1st hole is 2 cm away from the top side of the acrylic so that it causes a tilt angle on the hose installed so that the color Doppler signal can be visualized properly.

2. Blood Mimicking Material

The Blood Mimicking Material (BMM) used in this study is formulated from a mixture of aquades, glycerin, psyllium husk, and preservatives, with the aim of simulating the characteristics of human blood flow on ultrasound Doppler examination. The selection of such materials is based on considerations of availability, long-term stability, safety of use in educational settings, and their ability to produce a representative Doppler response to clinical conditions.

Blood Mimicking Material in a Phantom Doppler must be able to mimic the role of blood as a flow medium that contains scatterers, has the appropriate viscosity, and provides a stable and consistent Doppler signal. The combination of glycerin, aquades, and psyllium husk in this study was designed to meet all three aspects. Aquades is used as the basic medium in BMM formulations. The use of aquades aims to provide a liquid with high homogeneity, thus facilitating the mixing of other materials and maintaining the stability of flow in the phantom circulation system.

According to Tanaka et. Al. (2012), Glycerin in the formulation of Blood Mimicking Material (BMM) in this study has a very fundamental role, not only as a viscosity enhancer but especially as a regulator of fluid density and acoustic characteristics to approach the nature of human blood. Glycerin is added to the BMM as a liquid viscosity enhancer as well as an adaptor to the acoustic properties of the liquid. Glycerin has a higher density and viscosity than water, so it is able to increase the viscosity of BMM gradually and controlled. The viscosity of the

BMM has a direct effect on the flow velocity profile and the stability of the Doppler signal. BMMs with too low viscosity tend to produce too fast and under-representative flows, while too high viscosity can lead to attenuation of flow and decreased Doppler signal sensitivity. The results of observations during the study showed that the addition of glycerin in the composition of the BMM was able to produce a stable and easily interpreted Doppler spectrum, especially in Spectral and Color Doppler modes.

Another constituent of Blood Mimicking Material is Psyllium Husk. Psyllium husk is the main component that provides the scattering characteristics of BMM in this study. Psyllium husk is a natural fiber capable of forming colloidal structures and suspended particles when dissolved in water. This property is used to simulate the role of erythrocytes as the main scatterer. The psyllium husk in the BMM allows for the formation of more realistic Doppler signals than liquids without particles. The dispersed psyllium particles produce a scattering of ultrasound waves strong enough to produce a clear Doppler spectrum and color pattern in Color Doppler. The approach of using natural fibers or particles as scatterers has also been reported in several Phantom Doppler studies that focus on economical and easy-to-apply solutions.

3. Flow System on the Phantom

The flow system is an important component in the development of the Doppler phantom because it serves to simulate the movement of blood flow within the blood vessels. In this study, a flow system was made using 2 aquarium pumps connected by a hose as a medium that resembles the lumen of a blood vessel. Aquarium pumps were chosen because they have a simple working mechanism, are easy to obtain, and are able to produce continuous fluid flow so that they can be used to simulate blood flow.

In principle, aquarium pumps work by generating pressure that pushes the liquid to move through a hose or tubing system. The resulting flow then passes through the phantom part that acts as an artificial blood vessel, so that the scatterer particles contained in the blood-mimicking fluid (BMF) can move according to the direction of the flow that has been regulated. The use of aquarium pumps in this study also considers aspects of efficiency and ease of implementation in learning media. Compared to peristaltic pumps or special medical pumps that are commonly used on commercial phantoms, aquarium pumps are much more economical and easier to obtain. This makes it a potential alternative for the development of the Doppler phantom especially in the context of education for students. With a simple but functional flow system, students can understand the basic principles of Doppler examination, such as seeing color changes in the direction of flow visualized in Color Doppler mode.

However, the use of aquarium pumps in this study also has some limitations. Aquarium pumps generally produce flow patterns that tend to be continuous as shown in Figure 5.3. In Pulsed Wave Doppler mode, the flow speed in the phantom is 30 cm/s, in this case it corresponds to the velocity in the jugular vein. Aquarium pumps cannot always simulate pulsative flow patterns that resemble the physiology of blood flow in arteries. In addition, the stability of the flow rate can also be affected by the capacity of the pump and the configuration of the hose system used. Nonetheless, in the context of basic Doppler ultrasound learning, the flow system generated by the aquarium pump is still representative enough to produce observable and analyzed Doppler signals.

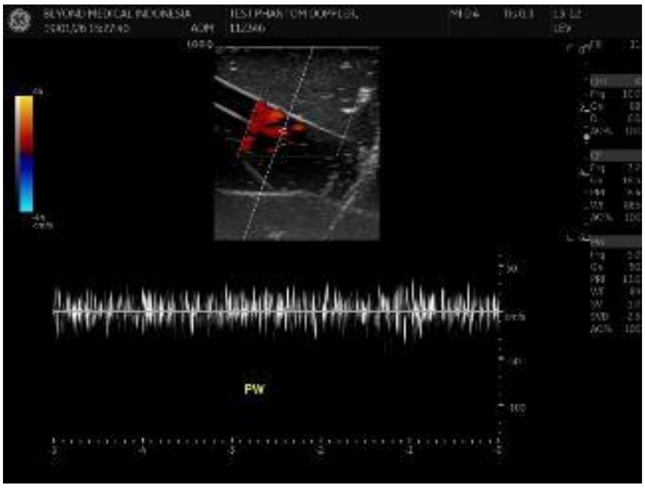

Figure 5. Measurement of flow velocity on a phantom using Pulsed Wave mode

Thus, the flow system using an aquarium pump on the Doppler phantom developed in this study can serve as a simple simulation of blood flow that allows visualization of Doppler signals on ultrasound examinations. This approach provides a more economical and practical solution in the development of phantom-based learning media, so that it can support the student practicum process in understanding the working principles of Doppler ultrasound in a more applicative manner.

4. Difference Between Conventional Gelatin and Simugel Gelatin

The comparison of Simugel and conventional Gelatin is shown in the following Table 3

Table 3. Comparison of Simugel Gelatin with Conventional Gelatin

Parameter Acoustics	Human Soft Tissue Targets	Gelatin Convensional	Gelatin Simugel
Speed of Sound	1540 m/s	1500 – 1650 m/s depending on concentration	1466 – 1540 m/s
Acoustic Impedance	1.63 MRayl	1.63 Mrayl as per gelatin concentration	1.64 MRayl
Attenuation Coefficient	0.5 – 0.7 dB/cm/MHz	0.015 – 0.15 dB/cm/MHz	± 0.13 dB/cm/MHz
Homogenitas Acoustics	Height	Medium	Height
Long-Term Acoustic Stability	Medium	Low	Height
Echogenicity	Resembles a network	Need to add a scaterrer substance	Optimal from manufacture

SimuGel is a commercial phantom material developed specifically for medical simulations and has mechanical and acoustic characteristics that resemble human soft tissue. Simugel is used because of its long-term stability, high reproducibility, and consistent elasticity. However, relatively high costs and limited availability are obstacles to its use as a learning medium in educational institutions. On the other hand, conventional gelatin has a more economical price, is easy to obtain, easy to modify, and is able to produce acoustic characteristics that are quite close to biological tissues but have a very short durability so they are less ideal for use as a simulation tool that can be used repeatedly.

Expert Test on Product Design

Based on the results of the research on the design of the phantom doppler, the test results were obtained that:

1. Aspects with excellent ratings

   Some aspects that have a value with a mean of 4.00 are as follows:

   a. The dimensions and shape of the phantom are considered suitable for student practicum activities, thus supporting the comfort and effectiveness of use during learning.
   b. The phantom design allows Doppler examination simulations to be performed repeatedly without compromising performance quality, demonstrating the durability and stability of the system
   c. Overall, the quality of the Doppler images produced was considered adequate for learning purposes, both in terms of visualization and display consistency.
   d. The Phantom is declared safe to use in learning activities, so it does not pose a risk to the user during practice.
   e. Phantom is considered suitable for use as a Doppler ultrasound learning medium for students, so it can be recommended as a means of simulation before clinical practice.

2. Aspects with Good Judgment

   a. The phantom design has been in accordance with the learning objectives of Doppler ultrasound and supports the achievement of students' basic competencies.
   b. The Phantom is able to display the difference in Doppler flow direction quite clearly, thus helping students understand the concept of positive and negative flow.
   c. The Phantom can be used to train basic Doppler examination skills, including probe placement and parameter optimization.
   d. Phantom is considered suitable for use as a simulation medium prior to practice in patients, demonstrating its clinical relevance.
   e. The phantom design facilitates the scanning process using ultrasound probes and considers ergonomic aspects of use during practicum.
   f. The Doppler image's response to changes in parameters such as gain, PRF, and wall filters is quite clear, supporting a learning process based on parameter exploration.
   g. Phantom supports the learning of Doppler angle setting and helps explain the relationship between Doppler theory and visual image display.
   h. In general, phanthoms are considered to have met the learning needs of Doppler ultrasound.

3. Aspects with sufficient assessment

The layout of the channel or vessel on the phantom is considered quite proportional, but there is still room for improvement in further development.

   a. The clarity of Color Doppler imagery and the Doppler spectrum is rated quite good, but it can still be improved to produce sharper and contrasting visualizations.
   b. Noise and artifacts in Doppler imagery are within acceptable limits for learning, although further optimization is still recommended.
   c. Support for Doppler spectrum interpretation learning is considered sufficient, but it can still be developed to be more optimal in the simulation of clinical conditions.

Overall, the results of expert tests show that the Phantom Doppler ultrasound developed is in the good to excellent category and is suitable for use as a learning medium. The majority of indicators obtained a score above 3.33, which indicates that the design, security, and quality of Doppler images have met the standards for practicum learning needs. This phantom is considered to be able to support simulation of repeated examinations, help students understand basic Doppler concepts, and facilitate technical skills training before clinical practice in patients. There are several technical aspects such as optimizing vessel layout and improving the clarity of Color and Spectral Doppler visualizations can still be improved. Improvements in this aspect have the potential to improve the quality of hemodynamic simulations and strengthen the function of phanthoms as a more comprehensive learning medium and closer to real clinical conditions.

User Phantom Practicality Test

Based on the results of the assessment of 30 respondents with 20 questions, an average score was obtained in the range of 3.46 to 3.87 (scale 1 to 4), which shows that phantom is in the category of very practical to be used in learning ultrasound practice.

1. Categories of Ease of Use

Based on the results of the practicality test, the ease of use aspect obtained an average score in the good to excellent category. Students consider that gelatin-based Phantom Doppler is easy to use and the operational procedures can be understood without requiring complicated explanations. This shows that the phantom design has considered the aspect of ease of operation in practical learning. Ease of use is an important factor in simulation media because it affects the effectiveness of learning. These results show that phantom has been able to support the learning process without causing significant technical problems.

2. Aspects of Doppler Image Clarity

The results of the student assessment showed that the Color Doppler image and the Doppler spectrum produced by the phantom were considered clear and representative enough for learning. Students can observe changes in flow direction as well as the response to Doppler parameter settings. Although the Doppler aspect of the spectrum obtained the lowest average score compared to other aspects, the score remained in the good category.

This shows that phantom has been able to simulate hemodynamic phenomena in an educational manner. The response to changes in parameters such as scale, gain, and Doppler angle showed that the flow system and the Blood Mimicking Material used had been working consistently. Thus, phantom can be used as a training tool in understanding the relationship between Doppler theory and image display in a practical way.

3. Aspects of Effectiveness of Use in Learning

Effectiveness in learning can be interpreted as the level of success of a medium in helping students achieve the learning goals that have been set. Based on the results of the practical tests that have been carried out, the bovine gelatin-based Doppler phantom shows a high level of effectiveness in supporting the learning of ultrasound practices, especially in Doppler materials.

Based on the results of the assessment from the respondents, the phantom is considered to be able to help students understand the basic concept of Doppler in a more concrete way. This can be seen from the assessment that shows that students can directly observe the relationship between insonation angles, flow directions, and changes in the Doppler spectrum. This visual and hands-on learning experience reinforces the understanding of concepts previously theoretically acquired in the classroom.

The effectiveness of the phantom is also judged by its ability to explore various Doppler parameters. Students can make adjustments to gain, PRF (Pulse Repetition Frequency), and Doppler angles, and then observe changes in image display in real-time. The effectiveness of learning can also be seen from increasing student confidence before conducting clinical practice on real patients. Respondents stated that the use of phantom helped them feel more prepared to perform Doppler examinations. This confidence is an important indicator in education, as it relates to mental readiness and decision-making ability during practice.

Based on all the indicators assessed, the Doppler phantom can be categorized as an effective learning medium. Phantom not only helps with concept understanding, but also improves students' technical skills, image interpretation skills, and readiness before practicing directly with patients. Thus, the development of this phantom has a significant contribution in improving the learning quality of ultrasound practice, especially in the practice of Doppler ultrasound.

CONCLUSION

Based on the research results, the Color Doppler phantom based on SimuGel™ was successfully developed as a simulation medium for ultrasound practical training and was found to be feasible, practical, and effective for educational use. The blood-mimicking material (BMM) formulation used in the phantom was able to produce flow characteristics and acoustic responses that supported the generation of representative Doppler ultrasound images. Expert validation results indicated that the phantom design, image quality, and functional performance met the requirements for educational applications. The practicality evaluation also demonstrated that the phantom was easy to operate and assisted students in understanding the concepts and skills required for Doppler ultrasound examinations prior to clinical practice. However, the phantom’s ability to reproduce physiological spectral Doppler patterns remained limited due to the use of a continuous, non-pulsatile flow system. Therefore, future research should focus on developing more precise pump mechanisms and flow control systems to improve simulation realism and expand the range of clinical conditions that can be represented.

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