Development and assessment of a carrageenan-based diagnostic ultrasound phantom

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Abstract –*Quality assurance (QA) ultrasound phantoms are essential in conducting equipment routine quality control and regular preventive maintenance, procedures that are important in ensuring the optimal performance of diagnostic ultrasound device. Using commercially-available ultrasound quality assurance phantoms in radiology departments, however, are primarily limited due to cost and resources constraints. In this study, a carrageen-based gelatin was investigated as an alternative ultrasound QA phantom. Carageenan or carageenins are derived from seaweeds that are commonly found in the Philippines. A rectangular container with dimensions of 5x5 inches was prepared and ninety grams (90g) of carrageenan-based gelatin (Lady's Choice Alsa Gulaman) were mixed to 250 mL of near boiling water (approximately 950C). The liquid mixture was transferred to a container, and the air bubbles were removed during the transfer. The targets were placed on the following positions: 1 inch, 2 inches, 3 inches, 4 inches, and 5 inches from the surface of the phantom. The target size used was 13.0 mm for button and 7.0 mm for pellets. The result of Mann-Whitney test at 95% confidence interval. The image quality scores for both button and pellet targets are not statistically different with a p value of .143. The developed phantom was evaluated in terms of its ability to produce diagnostically acceptable sonograms, determine sound penetration depth accuracy, horizontal and vertical measurement accuracy, and target size accuracy. Results of this study show that the carrageenan-based gelatine has a good potential as a base material in the development and construction of an ultrasound QA phantom.*

Keywords – *Gelatin-based phantom, phantom gel, quality assurance, quality control, ultrasound*

INTRUDUCTION

Medical ultrasound devices play important roles in the practice of modern diagnostic medicine. Unlike x-ray radiography, diagnostic ultrasound allows the physician to identify medical conditions safer and without the need to expose the patient to ionizing radiation. As with all other medical devices, consistent preventive maintenance and quality checks are essential in ensuring the safe, consistent and effective use of ultrasound devices. Image uniformity test, depth of signal penetration, and target visualization and distance accuracy are some of the commonly conducted quality control checks conducted on ultrasound devices [1]-[2]. Conducting ultrasound machine quality control typically involves the use quality control (QC) phantoms. These phantoms usually contain materials that allow the user to assess the ultrasound's image quality and the overall performance of the machine. Commercially-available quality control (QC) phantoms are normally constructed from tissue-mimicking materials like plastisols, pharmaceutical gels (poly-vinyl alcohol gels), fat-based gelatins, and synthetic polymers [3]-[14]. These materials mimic the properties of human tissues.

Using commercially available QC phantoms, however, is typically beyond access to small and medium-sized radiology facilities due primarily to cost and resource constraints. QC phantoms normally amounts to about a fifth of the overall cost of the actual diagnostic machine [5]. These phantoms often require meticulous handling preparation, careful storage and is handled by a specialized personnel (e.g diagnostic physicist) to effectively implement quality checks. Ordinarily, QC phantoms are found in large tertiary level diagnostic facilities employing several units of ultrasound machines.

The limited availability of ultrasound QC phantoms limits the wide spread implementation of important quality control testing diagnostic ultrasound. This exposes the facility to unnecessary downtime due to unforeseen machine failure that could have been prevented early quality control tests are regularly conducted [6].

The need, therefore, for a simple and cost-effective ultrasound QC phantom, which can be routinely used for conducting quality control tests is of primary interest in the field of radiologic technology.

Carageenan or carageenins are derived from seaweeds that are commonly found in the Philippines. According to Hurtado-Ponce [7], the Philippines is one of the world's largest producers of carageenan based on red seaweed. These seaweed-derived gels are widely used in the food industry as a gelling, thickening, and stabilizing agent. Commonly called "gulaman", the properties of carageenan gels are identical to that of the fat-based gelatins

This study is aimed to develop and assess a seaweed-based carrageenan gel as a simple ultrasound quality control phantom model. Specifically, it aims to assess the carrageenan gel phantom in terms of its ability to produce diagnostically acceptable sonographic images; determine accurate signal penetration depth, detect the target's horizontal and vertical location.

MATERIALS AND METHOD

Collection and Preparation of Carrageenan based Ultrasound Phantom

The plain carrageenan-based gelatin (Lady's Choice Alsa Gulaman) was purchased from a local supermarket. Alsa Gulaman (Figure 1) is the Filipino version of gelatin, which is used in the making of traditional desserts in the Philippines. Alsa Gulaman is prepared using dried agar, which in turn is a product made from red seaweed. Lady's Choice brand offers plain gulaman gelatins as well as coloured ones.

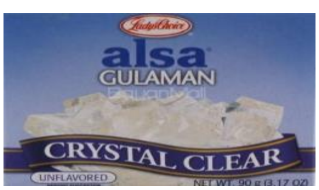

Figure 1. Alsa Gulaman

A rectangular container with dimensions of 5x5 inches was prepared. Ninety grams (90g) of carrageenan-based gelatin (Lady's Choice Alsa Gulaman) were mixed to 250 mL of near boiling water (approximately 95^{0}C). The mixture was continuously stirred for at least five minutes before it was allowed to cool down for around two minutes. The liquid mixture was transferred to a container while ensuring that air bubbles were removed during the transfer.

When the mixture was firm enough, the targets were placed on top of the cooled gel, after which a liquid carrageenan mixture was poured over the targets until it is already five inches thick. The same process was repeated until the targets were placed on the following positions: 1 inch, 2 inches, 3 inches, 4 inches,and 5 inchesfrom the surface of the phantom (figure 2). This method was employed for both button and pellet gun targets.

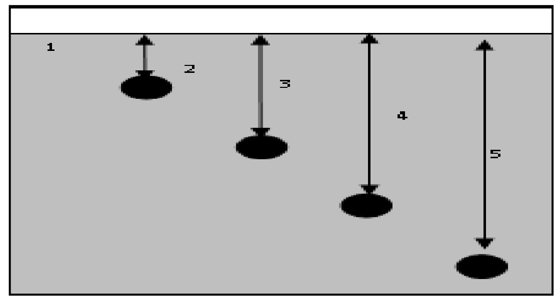

Figure 2.Schematic representation of the relative positions of the targets within the phantom. Values are expressed in inches

The prepared ultrasound phantom was initially placed inside a refrigerator (~5^{0}C) for at least one hour until the gelatin became firm enough to withstand the pressure of the probe during the testing. Figures 3-5 show the 5x5 container of the carrageenan mixtures and the actual positions of the button targets at 2 cm horizontal interval.

Figure3. Carragennan-based gelatin container

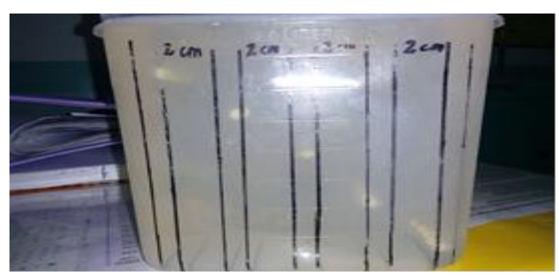

Figure 4. Photograph of gelatin image slab showing the actual placement of button targets at 2 cm horizontal interval

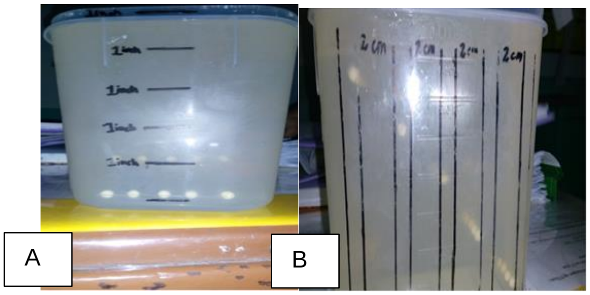

Figure 5. The actual position of the (A) button and (B) pellet targets within the phantom

Ultrasound procedure

A Siemens Aeusons X300 ultrasound machine using a 3.5 MHz curvilinear probe was used in this study. Ultrasound gel (Unimex gel) was applied to the curvilinear probe. Gloves were worn to protect the surface of the transducer. Another ultrasound gel was applied to prevent friction while rubbing the transducer to the developed ultrasound phantom.

The diagnostic properties of carrageenan-based phantom were characterized in terms of its ability to produce diagnostically acceptable sonographic images, accurately determining sound penetration depth, accurately detecting the target's horizontal and vertical location, and on accurately reporting the target.

Evaluation of Sonograms

A licensed and experienced radiologic technologist conducted the examination of the phantom. Ultrasound images were printed and were analyzed. The relative position of the targets with respect to the surface of the phantom was measured. Moreover, the horizontal distance between each target was also measured. The depth of penetration of the ultrasound signal was analyzed in terms of its ability to image the deepest target. The maximum depth of penetration was not determined in this study.

Table 1.
Criteria for the experts' evaluation of the diagnostic acceptability of the ultrasound images

Score	Criteria
1	No diagnostically acceptable image observed.
2	There is a diagnostically acceptable image observed but the image quality is poor
3	There is a diagnostically acceptable image observed and the image quality is good.

Sonograms were evaluated by experts consisting of five licensed and experienced radiologists. They blindly examined the diagnostic acceptability of the images produced using the scoring criteria shown in Table 1 [6]. Image uniformity test, depth of signal penetration, target visualization and distance accuracy were also observed by the radiologists. The target size used was13.0 mm for button and 7.0 mm for pellets.

Statistical Analysis

A two sample non-parametric test (Wilcoxon-Mann Whitney) was used to test the statistical significance of the ratings generated. All statistical correlation were based on Statistical Package for Social Sciences (SPSS) version 17 at p=0.05.

Results and Discussion

Diagnostic acceptability of the images is the most important criteria in imaging science. Table 2 shows the results of the evaluation of five expert radiologists on the image quality of the sonograms of pellet and button targets. It can be seen that the experts agreed on the quality of the image based on the resulting mean scores of 3 and 2.6 for the button and pellets, respectively.

This clearly shows that all the images presented are diagnostically acceptable to the strict requirements of experts and the target of interest is readily observable. This is more likely due to the carrageenan-based gelatin.

According to Kallel, et al [8] and De Korte et al. [9] Several studies have already shown that gels and gelatins are effective base materials in constructing QC phantoms, used agar and gelatin mixtures in developing heterogeneous phantoms. Their result showed that the speed of sound on the phantom is comparable to the speed of sound in the actual human tissues.

Table 2.
Descriptive Statistics the experts' image quality evaluation of the button and pellet sonograms

	N	Mean	Min	Max
Button Score	10	3	3	3
Pellet Score	10	2.6	2	3
Image Quality score	20	2.8	2	3
Grouping Var	20	1.5	1	2

The sonogram of the buttons and pellet targets at different depths from the surface of the phantom are shown on Figure 6 as evaluated on Table 2.

It is noticeable that the images buttons and pellets were clearly observed by the radiologist. This shows that the carrageenan-based phantom can produce diagnostically acceptable sonographic images.

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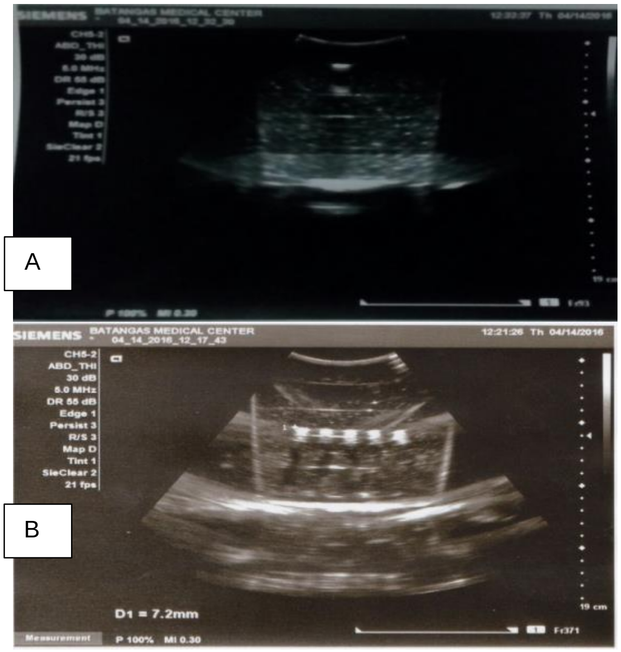

Figure 6.Ultrasound images of the buttons (A) and pellets (B) under ultrasound scan.

Table 3 present the result of Mann-Whitney test at 95% confidence interval. The image quality scores for both button and pellet targets are not statistically different with a p value of .143. This means that the diagnostic acceptability scores of the images indicate that carrageenan gel can be used as a base material for developing ultrasound quality control phantom.

Table 3. Mann-Whitney two – sample test statistics

Statistic	Image quality score
Mann-Whitney U	30
Wilcoxon W	85
Z-value	-2.179
p-value	.143

The results also show the feasibility of carrageenan to be a cost-effective material for determining the quality of ultrasound equipment. According to Goodsitt et al. [1], ultrasound machine should be monitored regularly to ensure its optimum performance, that is, it should continually produce diagnostically acceptable sonograms. The possibility of using carrageenan as a phantom material opens the opportunity to small and medium-sized radiology facilities to conduct routine QC test without the need to purchase expensive equipments. This reduces the risks of poor performance of ultrasound machines because regular monitoring of the equipment could be conducted.

Depth, horizontal measurement and size accuracy

Two trials were conducted to determine the ability of the ultrasound waves to reach the deepest position of the target within the phantom. The positions were labeled A to E with a corresponding 1-inch depth interval.

Table 4 consistently recorded the correct depths of both buttons and pellet gun bullets for all indicated depths. It was found out that all the targets depths, from 1 inch to 5 inches from the surface both for the pellets and buttons were distinctly observed. These results mean that ultrasound signals effectively penetrate the carrageenan-based gelatin, and have the capability to reach the target depths set in this experimental study. It can be deduced from the results that when the gelatin is used as ultrasound phantom, it has the capability of producing diagnostically acceptable images.

Table 4. Ability to observe of button and pellet targets as a function of depth from the phantom surface

Position	Depth* (inches)	Observable (Yes/No)
A	5	Yes
B	4	Yes
C	3	Yes
D	2	Yes
E	1	Yes

**Depth is measured from the surface of the phantom*

The gelatin could have been able to gain such positive results because it was firm and therefore was able to with stand the pressure of the ultrasound machine. Another reason for the capability of the carrageenan-based gelatin to attain depth is because carrageenan acts just like the plastisols, and pharmaceutical gels (poly-vinyl alcohol gels) which are used in commercial phantoms. According to Cournane et al. [10] commercially available ultrasound QC phantoms are normally constructed from polymer gels, such as plastisols and polyvinyl alcohol.

Table 5. Horizontal Measurement Accuracy of Carrageenan-based Gelatin Phantom

	Button		Pellet	
Refere nce	Meas. Separ Ation	True Separatio n	Meas. Separation	True Separ ation
A to B	2.4	2	2.6	2
B to C	2.4	2	2.4	2
C to D	2	2	1.6	2
D to E	2.4	2	2	2

Table 5 show that the carrageenan-based gelatin phantom using buttons as target showed consistent horizontal separation of 2.4 cm in segment A to B, B to C, D to E indicating a 0.4 increase from the horizontal separation of 2.0. While, layer C - D showed 2.0 cm horizontal separation as designated in this study.

As to the pellet gun bullets, there were observed variations on horizontal separation values which involved 2.6 cm for segment A and B, 2.4 for B and C, and 1.6 cm in C and D. The measured separation between segment D and E was measured to be 2.0cm, a value that is close to the designated distance of the targets.The possible cause of the differences lie in the positioning, placement, and the number of pellets used.

In general, the gelatin produced by the researchers has the ability to distinguish the target, an important function that is performed in ultrasound procedures. This is evident in the derived horizontal separation measurements.

The horizontal separation values manifest that the carageenan could distinguish its target. Its ability to image the anatomy of interest makes it a feasible base materialin developing phantoms for routine quality control checks of ultrasound machines. This is significant because ultrasound imaging is fast becoming the modality of choice in diagnostic radiology [11] and conducting routine quality control of ultrasound machine is now possible because the tools needed, such as the quality control (QC) phantom produced in this work, can now be readily available.

The test on horizontal separation values shows the capability of the carrageenan to get the correct image despite the differences in distance. According to Zagzebski [12], an important part of quality controlling clinical imaging is ensuring that equipmentare consistently operating on its expected level of performance.

Table 6. Size accuracy of carrageenan-based gelatin phantom

Target Type	Depth (in)	Actual Size (mm)	Meas Size (mm)	% diff	Pass/Fail
Button	5	13.0	13.3	2.3	Pass
	4	13.0	13.3	2.3	Pass
	3	13.0	13.3	2.3	Pass
	2	13.0	13.3	2.3	Pass
	1	13.0	13.3	2.3	Pass
Pellet	5	7.0	7.1	1.4	Pass
	4	7.0	7.1	1.4	Pass
	3	7.0	7.1	1.4	Pass
	2	7.0	7.1	1.4	Pass
	1	7.0	7.1	1.4	Pass

Table 6 shows the result of target size accuracy test. The measured size of the buttons is 13.3mm, a small difference of 2.31% difference from the actual value of 13 mm.

The scanned measurement of the gun pellets diameter 7.1mm, a 1.43% difference to the actual value of 7.0mm. These results indicate that the measured dimensions were not significantly different to the actual values. This implies that the ultrasound signals transmitted and received by the probe were not significantly attenuated by the gelatin medium. This is important because this illustrates that the carageenan gel was able simulate the sonographic properties of actual human tissue [13]. Kendall and Faragher [11] discussed that acceptable ultrasound phantoms should have the ability to transmit ultrasound waves without significantly reducing the received information. The material should also approximate the acoustic properties and sonographic appearance of actual tissues.

Conventionally, agar-based gels with suspended graphite, commercially available silicate gels, and polyurethane foam mimic the acoustic properties of tissue. These materials are traditionally used in commercially-available quality control (QC) phantoms. This study can now confidently claim that carageenan gels provide the same results found in commercial quality control (QC) phantoms. Furthermore, in terms of cost and ease of preparation, the gel used in this study is comparable to the results obtained by Earle et al. [14] using agar-based gels.

According to Lo et al. [6], the images produced should show the quality parameters of image uniformity, depth of penetration and visualization, and distance accuracy. Evidently as shown in the results, the carrageenan–based gelatin exhibited acceptable diagnostic images, making it a good alternative to the more expensive commercially available QC phantoms.

CONCLUSIONS AND RECOMMENDATIONS

Results of the investigation showed that the properties of the carrageenan-based gelatin produced good quality sonograms and provided diagnostically acceptable images. Furthermore, the phantom was able to provide accurate measurements on the depth of penetration, vertical and horizontal location, accurately reported target sizes.

Overall, the result of this experimental work shows that carageenan gelatin has a good potential as a base material for clinically prepared ultrasound QC phantoms. Further work, however, is needed to assess

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and determine the clinically acceptable working shelf life of the phantom.

It is recommended that the developed carrageenan-based gelatin be tried out and used to validate its capability to produce quality images. It is also suggested that further study on temperature be conducted on its archival potential for assurance of continued supply. Moreover, a parallel study may be conducted which may improve the properties of the carrageenan-based gelatin as quality assurance phantom.

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