Development and Evaluation of a Carrageenan-Based Training Phantom for Ultrasound-Guided Biopsy Procedure

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ABSTRACT: Training phantoms made from tissue mimicking materials play important roles in training and skills development of resident physicians in conducting ultrasound guided biopsy procedures. These training materials minimize the need to experiment in humans or animals and prevent unnecessary errors during actual biopsy. In this study, an inexpensive phantom model was constructed from carageenan-based gelatin and was used as a training material for ultrasound guided biopsy of radiology resident physicians. The phantom was evaluated in terms of its ability to mimic soft tissue sonographic images, ultrasound image quality, hand-eye coordination effectiveness, and on its overall acceptability as a training phantom in ultrasound guided biopsy procedures. Improvements in the scanning and sample retrieval time of the residents were observed after using the phantom.

Keywords: Ultrasound-guided biopsy, ultrasound phantom model, carrageenan, training phantom

INTRODUCTION

The demand for a safe and effective medical diagnosis, with minimum invasive intervention, is of paramount importance in the modern practice of medicine. Diagnostic ultrasound has been increasingly gaining widespread application in diagnostic medicine because of its relative safety compared to ionizing radiation-based modalities such as computed tomography (CT), x-ray radiography, and fluoroscopy (Kiessling et al., 2012). Additionally, diagnostic ultrasound more cost-effective compared to more advanced diagnostic modalities like magnetic resonance imaging (MRI) and positron emission tomography (PET-CT) procedures.

Recently, due to cost and safety concerns, ultrasound-based imaging has been gaining widespread attention, as a modality of choice in the area of image-guided biopsy procedures. Ultrasound-guided (US) biopsy procedures employ only high-frequency sound waves to localize the position of the targeted tissue. Compared to other modalities used in image-guided biopsy procedures, US-guided biopsy allows the physician to effectively gather tissue samples without the hazard of exposing the patient to high radiation dose (Bude et al., 1995).

In ultrasound-guided biopsy procedure, a small sample of tissue is removed from the body using a biopsy needle while an ultrasound probe is used to localize the position of the target. An image-guided biopsy is generally performed when an abnormal mass or lump has been found in an organ. Image-guided biopsy is a safe and a well-established technique in the field radiology and interventional medicine (Sutcliffe et al., 2013).

For a physician to expertly and safely conduct image-guided biopsy operation requires extensive training and practice. Extensive practice and comprehensive training are necessary to effectively conduct the procedure efficiently, to minimize potential hazards of the procedures, and lastly, to prevent fatal accidents on patients. Studies have indicated that training, especially involving training simulators are invaluable in developing the confidence and clinical competencies of physicians (Hocking et al., 2011).

Training phantoms found an important application in the area of the ultrasound-guided biopsy procedure (Pereira da Silva et al., 2015). Ideally, phantoms used in ultrasound-guided procedures should copy the acoustic and sonographic properties of actual human tissues (Hocking et al., 2011 and Bitarafan-Rajabi et al., 2014). Lastly, the training phantom also should be able to replicate the feel and experience of conducting the actual procedure (Hocking et al., 2011).

MATERIALS AND METHODS

Preparation of the Phantom

In this study, two sets of training phantom for ultrasound-guided biopsy was constructed. Two rectangular containers were provided. Balloons, maple syrup, food color, and psyllium fibers were used in the preparation of the phantom. One hundred eighty grams of carrageenan gelatin powder (lady’s choice alsa gulaman) was dissolved in 375 ml of distilled water. A food grade coloring was mixed to the gelatin to make the phantom optically opaque. This is done to prevent the user to visually locate the target within the phantom model.

The mixture was constantly stirred for at least five minutes while the mixture is being heated up to just before the boiling temperature. Upon reaching the desired consistency, the mixture is removed from the heat and was then allowed to cool for another three minutes. This was conducted to prevent air bubble formation in the mixture which would adversely affect the transmission of ultrasound waves when the gel solidifies. After three minutes, the mixture is poured into a 140 x 40 x 50 mm plastic container. The gel mixture was solidified at room temperature for at least 12 hours.

There were two sets of training phantom used in this study. The first one was used as a preliminary phantom for initial training of radiology residents while the second one was used for the final scanning. The total time needed to localize and remove part of the sample target was measured for each resident. The difference between the initial and final time for the total procedure was measured and a two sample-paired t-test was used for evaluating the statistical difference.

Description of the Phantoms

The first phantom used for the initial trial was prepared from a solidified carrageenan gel contained in a 140 x 40 x 50 mm plastic container. The phantom's surface was ensured to be as uniform as possible. Sample targets (seedless California grapes) were placed at different positions within the phantom. The locations were pre-determined and placed in a particular location based on the method proposed by Hernandez, et al (2016). The schematic diagram of the phantom is shown in figure 1. The first phantom was used only for target localization and served as a practice tool for probe and needle handling. Grapes were used as a sample target because no sample retrieval was intended.

For the second phase of the study, seven sets of phantoms were prepared in the same manner as described above but the locations of the target samples were randomly varied (except for the depth) to prevent memorization of the target position. Syrup-filled plastic balloons used in the second set-up because sample retrieval is expected from the respondents.

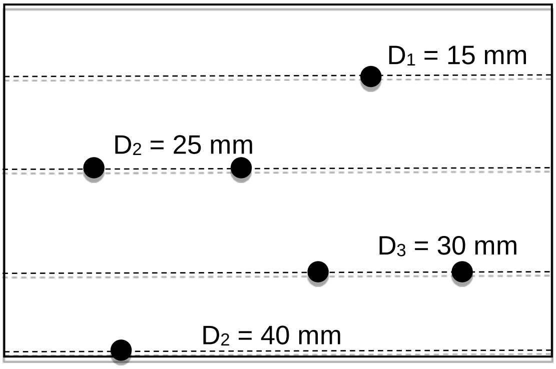


Figure 1. Schematic representation of the position of the grape targets within the targets. The depths were measured with respect to the phantom surface

Description of the Respondents

The respondents in this study were radiology residents of Batangas medical center and an expert radiologist who specialized in ultrasound-based diagnosis. In total there were six residents who participated. From the six residents, four are in their first year of residency while other two are already in their last year of training.

Residents' Measurement

For the first phase of the study, the residents were asked to use the phantom as an ultrasound tool for localizing the position of the target within the phantom. The residents were asked to locate and puncture the targets using needles. This is to allow them to practice hand and eye coordination and in the probe and needle handling. These skills are deemed important in ultrasound-guided biopsy procedures.

Seven phantoms were prepared, corresponding to the number of respondents who participated in this study. The total time it took for each respondent to locate all the targets and measure their corresponding sizes were timed. They were not informed that they are being timed to remove the undue pressure on their part. The study was designed in such a manner that the residents will work on the phase that they are comfortable with.

For the final phase of the study, the residents were again asked to locate the position of the targets, measure their sizes, and finally remove samples from the targets. The respondents were again blindly timed during the procedure.

All measurements were conducted in a Siemens Aesusons X30 ultrasound machine using 8.9 MHz curvilinear probe. An ultrasound gel (Unimex gel) was applied to the probe prior to the actual procedure. The settings used for thyroid examination was used in the procedure.

Phantom Evaluation

The developed phantoms were evaluated in terms of image quality as well as its ability to produce tissue mimicking sonographic images.

The respondents were asked to answer two sets of questions regarding the performance of the training phantom. The questions evaluated the phantom in terms of the quality of the images and the overall acceptability of the tool in radiology training.

Specifically, the respondents were asked to answer whether they agree with the following general statements that the phantom

a. can produce good sonographic images identical to actual human tissues,
b. improve the confidence of the resident trainee in conducting ultrasound guided biopsy procedures
c. improve the hand and eye coordination of the resident trainee
d. can be an effective training material in an ultrasound-guided biopsy procedure
e. can be recommended as a training phantom in radiology training

RESULTS AND DISCUSSION

The vertical locations of the targets were initially measured. Identifying the location of the target within the tissue is an important part of target localization. This is important in the proper selection of the tools needed (e.g. needle) in the actual biopsy procedure. The results of the data are shown in table 1 and table 2. The percent error between the measured depth and actual depth was measured using the equation

$$\%\ \text{error} = \left| \frac{\text{AV - MV}}{\text{AV}} \right| \times 100\%$$

Where
AV = actual value
MV = measured value

Table 1. Resident's measurement of target's depth within the phantom

Actual Depth	1	2	3	4	5	6	Ave	% Error
15	10	0.97	12.5	12.9	17.3	14.2	11.3	32.61
25	14.7	13.6	24.8	26.6	34.9	25.7	23.4	6.91
30	37.7	27	28.4	27.2	46.3	27	32.3	7.0
40	43.6	40.8	42.1	42.2	48.6	40.8	43	7.01

Measurement are reported in millimeters (mm)

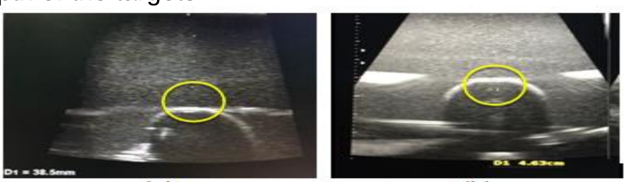
Table 2. Radiology consultant's measurement of target's depth within the phantom

Actual Depth	Consultant	% Error
15	14.2	5.33
25	25.7	2.80
30	26.8	10.7
40	38.5	3.75

Measurement are reported in millimeters (mm)

The calculated percent error between the actual and measured value have a maximum value of 32.61% and a minimum value of 2.80%. In general, larger percent errors were observed on the measurements of junior residents while that of the consultant were generally closer to the actual values. The inter-variability in the measurements were due to the different ways in which they select the reference point in the image. For instance, the reference point selected by a particular respondent was significantly different to the point selected by the consultant (see figure 2).

The results of depth measurement show that the values obtained by the both residents and consultant approximate the actual depth of the targets.



(a) (b)

Figure 2. The discrepancy in the reported depth of the target is due to the respondent's selection of the reference point

The results obtained from depth measurements successfully shown that the relative positions of the targets from the surface of the phantom were accurately measured. Precise knowledge of the spatial position of the target is important in tumor or target localization. Additionally, knowledge of target location assists physicians in designing the best treatment modality and intervention to the patient.

Relative echogenicity of simulated targets and biopsy needles

In radiology, the information that can be derived from diagnostic images is important in formulating the appropriate clinical decision. Similarly, conducting image-guided biopsy operations require that the images should provide vital information needed to implement the intended procedure. In this respect, the images should be able to delineate the tumor or target from the other tissues and organs. Furthermore, the spatiotemporal position of biopsy needles relative to the target should be known in real time.

To assess whether the developed phantom can be of practical use in image-guided biopsy training, the relative echogenicity of the targets and needles with respect to the carrageenan gel was evaluated. Echogenicity is the ability of the material to reflect back ultrasound signals (Ihnatsenka, B and Boezart, AP, 2010). Relative echogenicity of the materials is important in the formation of subject contrast in the image (Hocking et al, 2011). A training phantom intended for ultrasound-guided biopsy should have targets with different echogenicity to be able to delineate objects within the phantom.

Figure 3 shows the ultrasound images of the targets and needles within the gelatin background of the phantom. It can be observed from the figures that the simulated targets and needles were visually distinguishable from each other and from the background material. The needle appears brighter (hyperechoic) while the target appears gray (hypoechoic) on the screen. Hyperechoic objects reflect ultrasound signal better than hypoechoic materials (Ihnatsenka, B and Boezart, AP, 2010). The relative echogenicity of the target and the carrageenan gel provided image subject contrast between the two. This subject contrast is needed in the delineation of the target, the needle, and the background.

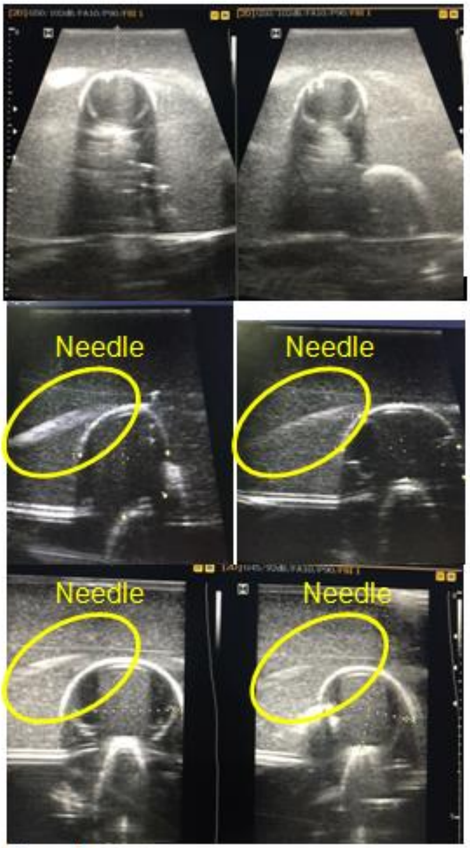


Figure 3. Simulated soft tissue targets are distinguishable from the carrageenan gelatin base material of the phantom

Scanning Time Measurement

One of the important objectives of using training phantoms in ultrasound-guided biopsy procedures is to improve the confidence and speed of the residents in conducting the procedures. In this work, the respondents were asked to use locate and puncture the targets using needles. This is to allow them to practice hand and eye coordination and aid in probe and needle handling, skills which are very important in ultrasound biopsy procedures. They were, afterward, asked to remove samples from the second set of identical phantoms. The respondents were blindly-timed during both procedures. The time-trial results are shown in table 3.

To determine whether the difference in time-trial measurements were statistically significant, the results were compared using a paired t-test. The result of the test is illustrated in table 4.

Results of the measurement show that the respondent's biopsy procedure time significantly decreased after initial practice. The time reduction is between 14 seconds to 150 seconds. These results imply that doing initial training significantly reduced the the total time the residents' needed to complete the procedure (see table 4). It can be surmised that this time reduction can be attributed to the increased confidence and in the improvement of hand-eye-probe coordination of the user. These results were comparable to the results of Filippou, et al (2016) and Sutcliffe et al (2013) where they observed that hands-on training and use of training phantom increases residents' skill and confidence in conducting ultrasound-guided procedures. Similarly, they also observed that trainees who undergone initial training performed better and works faster compared to those who did not

Residents' qualitative evaluation of the training phantom

To further evaluate the usefulness and acceptability of the training phantom in radiology training, the respondents were asked to respond to the statements regarding the phantom. The statements dwell on two categories. One whether the sonographic images of the phantom are diagnostically acceptable and, two, whether they agree that the phantom is useful in radiology training. The results of their responses are shown in table 5.

It can be seen from the results that the respondents unanimously agree that the phantom's sonographic images were diagnostically acceptable. More than sixty-two percent (62%) of the respondents strongly agree that the ultrasound images were able to mimic the sonographic appearance of human tissues. Furthermore, half of the respondents agree that the targets somehow appear like actual cysts or tumors.

In terms of the phantom's usefulness as a training tool in radiology training, majority of the respondents agree that the phantom was able to simulate the actual experience of inserting the biopsy needle, improve their hand-eye coordination and confidence in doing the procedure. And finally, all of them strongly agree that training phantoms should be included in radiology training and believes that this is helpful in improving the skills of resident trainees

CONCLUSION

In this study, an inexpensive phantom model was constructed from carageenan-based gelatin and was used as a training material for ultrasound guided biopsy training. The developed phantom exhibited good sonographic images of the simulated targets and were able to aid the resposndents in needle insertion and target localization. Relative echogenicity of the materials with respect to each other and the background allowed accurate delineation of the targets. The training phantom also aided the respondents on the improvement of their skills and efficiency in conducting image-guided biopsy procedure. Lastly, the phantom received unanimous acceptance from radiology residents as a useful tool for biopsy training.

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