Use of Novel Anthropomorphic Breast Ultrasound Phantoms for Radiology Resident Education

Jacinta Browne
Technological University Dublin, jacinta.browne@tudublin.ie

Chris Gu
Mayo Clinic

Robert Fazzio
Mayo Clinic, fazzio.robert@mayo.edu

Andrew Fagan
Mayo Clinic, faganan@tcd.ie

Donald Tradup
Mayo Clinic

See next page for additional authors

Recommended Citation

Browne, Jacinta E. et al.(2019) Use of Novel Anthropomorphic Breast Ultrasound Phantoms for Radiology Resident Education. *Journal of the American College of Radiology* 16.2 (2019): 211-218. doi.org/10.1016/j.jacr.2018.08.028

Jacinta Browne, Chris Gu, Robert Fazzio, Andrew Fagan, Donald Tradup, and Nicholas Hangiandreou

Use of novel anthropomorphic breast ultrasound phantoms for radiology resident education

Jacinta E. Browne[1a], Chris Gu[2b], Robert Fazzio[2], Andrew J. Fagan [1,2], Donald J. Tradup[2], Nicholas J. Hangiandreou[2].

[1]Medical Ultrasound Physics and Technology Group, IEO, FOCAS, Dublin Institute of Technology, Ireland

[2]Department of Radiology, Mayo Clinic, Rochester, Minnesota, U.S.A.

[a] Corresponding author

[b] Currently in University of Pittsburgh Medical Center Department of Radiology

Corresponding author

Dr. Jacinta Browne,

Department of Radiology, Mayo Clinic, Rochester, Minnesota, U.S.A

E-mail: jacinta.browne@dit.ie or browne.jacinta@mayo.edu

Telephone : +353 14024737

Acknowledgements

JEB and AJF would like to acknowledge funding from Enterprise Ireland Commercialisation Fund, grant number CF2013 3308.

Dr. Browne and Dr. Fagan reports grants from Enterprise Ireland - Commercialisation Fund, from null, during the conduct of the study; in addition, Dr. Browne has a patent UK Patent Application No: 1713229.1 pending.

Dr. Gu, Dr. Fazzio, Mr Tradup and Dr. Hangiandreou have nothing to disclose.

Abstract

Purpose: This study evaluated the training and assessment role of anthropomorphic breast ultrasound phantoms which simulated both the morphological and sonographic characteristics of breast tissue, including lesions, in a group of radiology residents at a large academic medical center. **Methods:** This was a prospective study involving 9 residents across all years (2nd–4th year) of a radiology residency program. Baseline assessments of all residents ability to detect and characterize lesions in P-I were carried out, followed by a two-hour teaching session on the same phantom. All residents underwent a post-training, final assessment on P-II to evaluate changes in their lesion detection rate and ability to correctly characterize the lesions. The two devices (Phantom 1 (P-I) and Phantom 2 (P-II)) were designed and constructed to produce similar realistic sonographic images of breast morphology with a range of embedded pathologies to provide a realistic training experience. **Results:** The results demonstrated there was a significant increase in both the pooled detection and correct characterization score for all residents pre- and post-training of 26±14% and 17±8%, p<0.0003, respectively. Post-training assessment surveys revealed that residents rated the training experience highly. **Conclusions:** This study suggests that there is a benefit in including a simulation training workshop with a novel anthropomorphic breast ultrasound training device to a radiology resident education program. Finally, the phantoms used in this study are useful for training and assessment purposes as they provide a life-like simulation of breast tissue to practice ultrasound imaging without direct exposure to patients, in a non-pressured environment.

Key words: breast ultrasound imaging; clinical competency; education; anthropomorphic training phantom; breast tissue mimicking materials.

Introduction

Medical education encompasses the integration of often complex theory with clinical hands-on practice and the development of key competencies for the medical environment. It is of paramount importance that medical students and residents develop these key competencies in an effective manner, utilizing didactic and clinical learning strategies. In medicine, evaluation of training needs together with efforts to maintain patients' safety, coupled with rapid advances in technology, led many disciplines to evaluate and validate both virtual simulation technology and anthropomorphic phantom technology (1). The use of both virtual simulation, anthropomorphic phantoms and ex-vivo chicken breasts is an integrated learning approach, such as the Kolb's Cycle of experiential learning which is being successfully used in many ultrasound guided breast biopsy training programs, which is particularly important when learning such complex tasks as hand-eye coordination (2-7). In particular, it has been found that when students learn complex task in an integrated manner, it is easier for them to transfer what they have learned to the reality of day-to-day work settings (5, 8, 9). However, the ex-vivo chicken breast phantoms do not possess the complex anatomical shape or a range of internal morphology to learn from. In diagnostic ultrasound, a limited number of ultrasound simulators and training (basic and anthropomorphic) phantom devices have been developed to train radiology residents in breast ultrasound diagnostic scanning which encompasses detection and characterization of lesions. One such anthropomorphic breast phantom used in radiology resident training of breast ultrasound procedures has shown improvement in development of technical skills in residents and how the use of such a device can help the resident to develop their detection skills to the level of an expert (5). The quality of ultrasound examinations is highly dependent on the knowledge, skill, and experience of the operator due to the hands-on and real-time nature of the modality. Thus, training typically takes place on-the-job, in a busy clinical environment, by shadowing an experienced radiologist or sonographer. This approach offers limited tactile feedback with limited acquisition of motor and eye-hand co-ordination skills, and does not afford trainees the opportunity to master the complex ultrasound scanning skills for the plethora of ultrasound imaging examinations. Furthermore, the complexity and rapid pace of development of ultrasound technology poses an additional challenge for the trainee to this field.

However, in the work setting, residents must also develop good hand-eye coordination and 3D psychometric manipulation skills required for diagnostic imaging and image guided procedures. The aim of this prospective case study was to investigate the impact of including a 3-hour breast ultrasound training workshop, utilising anthropomorphic breast phantoms (one for initial assessment and training and second for final assessment) which simulated sonographic characteristics of breast tissue, including benign and malignant lesions, in a group of radiology residents at a large academic medical center.

Methods

This prospective observational case study involved 9 diagnostic radiology residents (4th year resident, n=3; 3rd year resident, n=3; 2nd year resident, n=3) at a large medical institution. Participation was voluntary, resident anonymity was maintained and research was approved by the institutional ethics committee. Prior to the pre-simulation training assessment, each resident was interviewed to ascertain their level of experience in ultrasound imaging and breast ultrasound. The training workshop session had three distinct phases, with each resident undertaking each phase as outlined in the flow chart depicted in Figure 1.

Haptic Device – Anthropomorphic breast ultrasound phantom

The quality of training achieved using haptic devices, such as the anthropomorphic breast training phantom described in this study, is linked to the quality and realism of the haptic device. Therefore, to incorporate "**best practice**" into the design of the haptic device, 9 of the 10 features identified by McGaghie et al., 2010 as being key to the success of the training experience were incorporated into our methodology (10); in summary, each feature contributes to providing a period of deliberate, self-directed practice of authentic training tasks which constructively align with the radiology resident curriculum.

Two anthropomorphic breast ultrasound phantoms (P-I and P-II) were designed and constructed for this study (Figure 2). The phantoms were composed of an agar-based tissue mimicking material with different quantities of glycerol, aluminum oxide and silicon carbide particles depending on the type of breast tissue or lesion which was being replicated. The glycerol altered the speed of sound, while the aluminum oxide and silicon carbide particles altered the attenuation and relative backscatter of the different tissue components with the phantom. The phantoms were composed of materials mimicking skin, subcutaneous fat, Cooper's ligaments, fibroglandular and retromammary layers, with similar acoustic properties to the corresponding breast tissue, with simulated malignant and benign lesions (including fibroadenomas, cysts and calcifications) embedded within the fibroglandular layer. For a full description of the construction of these phantoms refer to Browne et al 2017. Both P-I and P-II were designed to produce realistic sonographic images of breast morphology of the range of embedded pathologies distributed at known locations within the phantom. P-I and P-II contained the same type of benign and malignant-mimicking lesions but located in different areas within the phantom.

Baseline Assessments

Pre-training performance assessments with the anthropomorphic breast phantom were obtained for each resident at the start of the breast ultrasound training workshop. The 3-hour breast ultrasound training workshop sessions were one-to-one with a resident and one instructor (the same instructor carried out all the training workshop sessions). Each resident was given an overview of the anthropomorphic breast ultrasound phantom design and the workshop plan, as well as a description of the pre-simulation training task which they had to undertake. However, no instructions as to how to approach the task was given to the resident in order to determine the resident's performance based on previous experience and training. The residents were then asked to carry out a breast ultrasound examination using a ML6-15 transducer with a GE Logiq 9 ultrasound machine (General Electric, USA) which had similar performance and pre-sets to those used in the breast ultrasound imaging clinical practice. Each resident optimized the phantom images as they felt appropriate with no guidance proffered by the instructor during the assessment pre-simulation training. Residents were blinded to the numbering and position of lesions in the device and were informed that they were to report any clinically relevant findings (lesions, calcifications, etc.) in terms of the clock face position, distance from the nipple and depth of lesion for the detection part of the assessment task. Once detected, they were to characterize each of the detected lesions based on the BI-RADS v5 lexicon (a copy of which was provided for reference during the workshop). Identification and characterization of each lesion was documented by the instructor and compared against the P-I specifications for calculating the detection and characterization score of each resident. The assessment rubric utilized was as follows: Detections were scored as true-positives (+10), false-positives (-10) and duplicate detections, and the weighted lesion characterization score was composed of the score for the lesion detection combined with the correct identification of the shape (+2), margin contour (+2), echogenicity (+2), orientation (+2), posterior effects of the lesions and presence of calcifications (+2). The instructor also took observation notes recording technical performance for each resident in terms of probe manipulation and scanning approach, and the rate at which residents changed the ultrasound system controls and attempted to optimize the image quality.

Training and Practice Session

Following the baseline assessment, each resident undertook a self-directed training and deliberate practice session using the anthropomorphic breast ultrasound phantom that they were assessed with. During the training and practice session the residents were shown were the lesions were located and details of the characteristic features of the lesions, along with representative ultrasound images of each lesion within P-I. The residents were instructed and given material on breast ultrasound scanning techniques, the BI-RADS lexicon and details of the location and characteristic features of the lesions embedded in P-I, together with representative ultrasound images of each lesion within P-I. During the practice session, the residents were encouraged to ask questions and to practice using the equipment themselves.

Final Assessment

Final assessments were undertaken for each resident at the end of the breast ultrasound training and practice session. Each resident was asked to carry out a breast ultrasound examination on P-II using the same ultrasound scanner used for P-I. As before, the residents optimized the phantom images as they felt was appropriate, with no guidance proffered by the instructor during the assessment post- simulation training. Residents were informed that they were again to report any clinically relevant findings (lesions, calcifications, etc.) as before, and to characterise each of the detected lesions based on the BI-RADS v5 lexicon.

Identification and characterization of each lesion was documented by the instructor and compared against the P-II specifications for calculating the detection and characterization score of each resident. Observation notes recording the technical performance were also recorded.

Evaluation of Training and Assessment Workshop

Following the final assessment, the residents were asked to complete a survey of the training and assessment workshop using a 5-point Likert scale; the questions which the residents were asked, and the average scores are presented in Table 1.

The questionnaire was used to determine how the residents' perceived the use of the anthropomorphic breast ultrasound training device in terms of improving their integration of ultrasound theory into practice, and whether they felt more confident operating an ultrasound system. This questionnaire represented Level 1 on the Kirkpatrick Evaluation Tool and is commonly known as a "Happy Sheet"(11). The purpose of this questionnaire was to gauge the simulation training workshop's impact and potentially to serve as a framework for future changes to the pedagogical approach implemented for achieving the learning outcomes and competences from the Residency Program.

Statistical Analyses

Statistical analyses were carried out using a dedicated software (SPSS, IBM, Armonk, NY, USA). Independent sample t-tests were used to compare lesion detectability and characterization of the residents' pre- and post-simulation training.

Results

Pre- and post-simulation assessment revealed a significant increase in the radiology residents' detection scores, with a pooled increase in detection score of 26 ± 14 %, $p < 0.003$ as presented in Figure 3(a). Furthermore, as shown in Figure 3(a), no significant difference was found between the 2nd, 3rd or 4th year residents; this was not surprising as the average breast ultrasound imaging experience for each year was very small, specifically, 0, 4 and 8 weeks, for the 2nd, 3rd and 4th year residents, respectively.

Furthermore, it was found that there was a moderate increase in the radiology residents' weighted lesion characterization scores pre- and post-simulation training, with a pooled increase in detection score of 17 ± 8 %, $p < 0.003$ as presented in Figure 3(b). Again, no significant difference was found between the 2nd, 3rd or 4th year residents' ability to characterize the lesions.

Furthermore, the residents benefited from the simulation workshop session in terms of an improvement in their 3D psychometric manipulation skills, which was demonstrated by the decrease in the number of lesions which were detected more than once and mistaken as new lesion detections, as presented in Figure 3(c). In general, the same lesions were detected repeatedly by the residents; these particular lesions were located centrally within the phantom, and therefore could be seen from multiple clock-face positions as the ultrasound transducer was scanned around the phantom, leading to the multiple repeated detections. Similar lesions were present in both P-I and P-II, specifically included to assess the residents'3D psychometric manipulation skills pre- and post-simulation training. Each of the residents demonstrated an improvement in their scanning technique during the post-simulation training assessment, in particular transducer movements were smoother, with adequate orientation and placement of the transducer, and they demonstrated an improvement in technical performance through increased use of image optimisation controls.

The summary of the post-simulation assessment responses are presented in Table 1.

Discussion

In this pilot study, a case study methodology was employed to investigate the use of a simulation training workshop as part of a residency training program in a large medical centre and to determine its pedagogical impact. For this research study, this methodology was deemed most fitting, as it allowed the researcher to focus on human behaviour (i.e. of the radiology residents) and meaning (i.e. impact of an anthropomorphic breast ultrasound training device), in a real-life setting to gain a deeper understanding of this central phenomena (12-16).

Training using simulation technology, such as an anthropomorphic breast ultrasound training phantom or a simulation laboratory, offers a novice trainee an opportunity to mature into a “pre-trained novice” (17). A pre-trained novice is an individual who has been trained using simulation to the point where many of the complex skills such as the psychomotor navigation skills and interpretation of 3D objects in 2D images required for ultrasound imaging have been automated and occupy fewer cognitive resources. This allows a novice trainee to focus on higher level learning in the ultrasound scanning room, such as taking a systematic scanning approach, performing image optimisation via instrument control, and performing image interpretation. Furthermore, training using simulation technology provides trainees with the opportunity to engage in deliberate practice, a key aspect of adult learning theory and philosophy. In this study, a statistically significant improvement in both lesion detection (26 ± 14%, $p<0.003$) and characterisation (17 ± 8%, $p<0.003$) was found through deliberate practice using anthropomorphic breast ultrasound phantoms. This period of deliberate practice using the anthropomorphic breast ultrasound training device provided the residents with an opportunity to refine their technical skills of manipulating the ultrasound transducer and interpreting the 3D space of the anthropomorphic breast phantom. The current training practice in most medical residency programs is that the residents undertake an apprenticeship teaching model which does not provide the learner with an opportunity to learn through deliberate self-directed practice in a non-pressurised environment; this latter approach is provided using an anthropomorphic breast ultrasound training device. The 3D psychometric manipulation skills of the residents were found to improve, as determined from qualitative observational notes which recorded the resident’s transducer manipulation and technical performance (image optimization).

The simulation training workshop was carried out over a block of 3 hours, chosen in part to facilitate the recruitment of radiology residents, but also because this time duration was found, in a meta-analysis of 63 studies performed by Donovan & Radosevich, 1999, to be the optimum set-up and practice time for learning complex skills such as ultrasound imaging (18); this meta-analysis revealed that the effect of training intervention over a distributed practice schedule diminished with increased task complexity and increasing time interval between practice sessions. The ultrasound scanning skills which were being developed and assessed through the simulation training workshop in this study were complex, and so it was hypothesised that the approach of a massed training session would provide the best results compared to distributed practice which was how our previous study was carried out (19).

Overall, the level of confidence reported by the residents for each of the three main training aspects (i-iii) was 4.1 / 5. Furthermore, the two questions (iv-v) relating specifically to the simulation training workshop scored a very high satisfaction level from the participants of 4.7 /5, indicating that the majority of residents felt that this pedagogical approach served as a valuable training experience for this technically and conceptually difficult subject of breast ultrasound imaging.

In conclusion, the anthropomorphic breast phantoms were found to be useful for training and assessment purposes by providing a “life-like simulation” of breast tissue for ultrasound imaging in a non-pressurized environment. This allowed radiology residents to practice ultrasound imaging without direct exposure to patients, thus refining their ultrasound scanning skills. This study demonstrates the utility of “life-like” ultrasound breast phantoms in the education of resident physicians and their ability to accurately and confidently detect breast lesions.

Limitations

There are a number of limitations associated with our study. Firstly, this training was not included as part of the residency program and timed to occur at the same time as didactic lectures on ultrasound imaging and no pre- and post-knowledge assessments were conducted to determine if the workshop improved the resident’s knowledge of ultrasound. Secondly, no follow-up was carried out to determine the impact this training had on the resident’s clinical competency in scanning patients. Finally, given the study population size the results may not be generalizable although the careful consideration of the case study design should counter this. However, a larger-scale study across multiple sites could be performed to better assess the impact of this type of training intervention.

Take-Home Points

- In our experience, there appears to be a benefit in including a simulation training workshop utilizing an anthropomorphic breast ultrasound training device to radiology resident education programs.
- It was found that this pedagogical approach afforded residents with the opportunity to carry out periods of self-directed, deliberate practice using an inanimate object which precisely mimics both the anthropomorphic shape of the breast which helped them to refine their scanning skills and was found to improve their ability to detect and characterise lesions embedded within the training device.
- It was found that this type of simulation training workshop had a positive impact on the residents' self-reported confidence.

REFERENCES

1. McGaghie WC, Issenberg SB, Petrusa ER, Scalese RJ. A critical review of simulation-based medical education research: 2003–2009. Medical Education. 2010;44(1):50-63.
2. Kolb AY, Kolb DA. Experiential learning theory. Encyclopedia of the Sciences of Learning: Springer; 2012. p. 1215-9.
3. Maran NJ, Glavin RJ. Low-to high-fidelity simulation–a continuum of medical education? Medical education. 2003;37(s1):22-8.
4. Maudsley G, Strivens J. Promoting professional knowledge, experiential learning and critical thinking for medical students. Medical education. 2000;34(7):535-44.
5. Mendiratta-Lala M, Williams T, de Quadros N, Bonnett J, Mendiratta V. The use of a simulation center to improve resident proficiency in performing ultrasound-guided procedures. Academic radiology. 2010;17(4):535-40.
6. Harvey JA, Moran RE, Hamer MM, DeAngelis GA, Omary RA. Evaluation of a turkey-breast phantom for teaching freehand, US-guided core-needle breast biopsy. Academic Radiology. 1997;4(8):565-9.
7. Gresens AA, Britt RC, Feliberti EC, Britt L. Ultrasound-guided breast biopsy for surgical residents: evaluation of a phantom model. Journal of surgical education. 2012;69(3):411-5.
8. Prideaux D. Integrated learning. A Practical Guide for Medical Teachers 3rd ed Edinburgh, UK: Elsevier. 2009:181-6.
9. Hassard MK, McCurdy LI, Williams JC, Downey DB. Training module to teach ultrasound-guided breast biopsy skills to residents improves accuracy. Canadian Association of Radiologists Journal. 2003;54(3):155.
10. McGaghie WC, Issenberg SB, Petrusa ER, Scalese RJ. A critical review of simulation-based medical education research: 2003–2009. Medical education. 2010;44(1):50-63.
11. Steinert Y, Mann K, Centeno A, Dolmans D, Spencer J, Gelula M, et al. A systematic review of faculty development initiatives designed to improve teaching effectiveness in medical education: BEME Guide No. 8. Medical teacher. 2006;28(6):497-526.
12. Yin RK. Case study research: Design and methods: Sage publications; 2013.
13. Picard M, Nelson R, Roebel J, Collins H, Anderson MB. Use of Low-Fidelity Simulation Laboratory Training for Teaching Radiology Residents CT-Guided Procedures. Journal of the American College of Radiology. 2016;13(11):1363-8.
14. Cousin G. Researching learning in higher education: An introduction to contemporary methods and approaches: Routledge; 2009.
15. Cavaye AL. Case study research: a multi-faceted research approach for IS. Information systems journal. 1996;6(3):227-42.
16. Denscombe M. The good research guide: for small-scale social research projects: McGraw-Hill Education (UK); 2014.
17. Gallagher AG, Ritter EM, Champion H, Higgins G, Fried MP, Moses G, et al. Virtual reality simulation for the operating room: proficiency-based training as a paradigm shift in surgical skills training. Annals of surgery. 2005;241(2):364.
18. Donovan JJ, Radosevich DJ. A meta-analytic review of the distribution of practice effect: Now you see it, now you don't. Journal of Applied Psychology. 1999;84(5):795.
19. Browne JE, Cannon LM, McDermott R, Ryan M, Fagan AJ. Pilot Investigation into the Use of an Anthropomorphic Breast Sonography Phantom as a Training and Assessment Tool. Ultrasound in Medicine and Biology. 2017;43(11):2733-40.

Figure 1: Flow chart of the different phases of the training workshop undertaken by each resident.

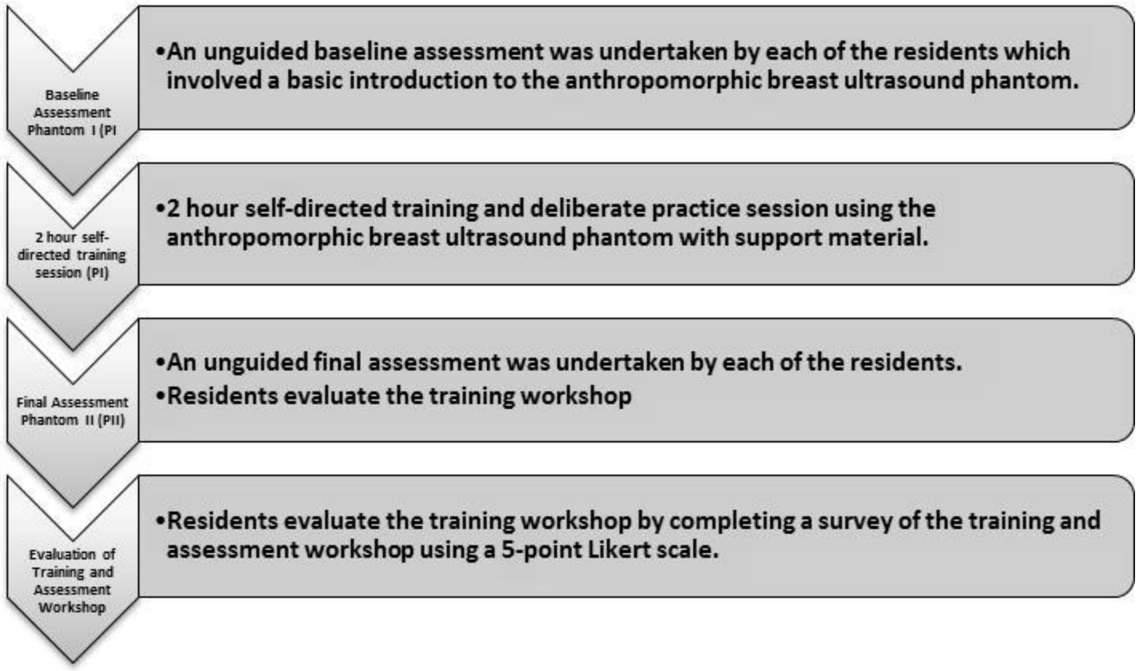

Figure 2: Anthropomorphic breast ultrasound phantom training device used in this study. (a) Photograph of the anthropomorphic phantom, (b) representative sonographic image from one of the phantoms, revealing the simulated layering and anatomical features typically observed *in vivo* and (c) representative images from one device: (a) shows an oval anechoic mass with circumscribed margin and absence of posterior acoustic features. Also visible are skin (S), Cooper's ligaments (CL), subcutaneous fat (SF), fibroglandular (F) and retromammary fat (RF) layers. (b) shows a coarse calcifications with marked posterior acoustic shadowing. (c) shows an anechoic, round mass with circumscribed margins and no posterior acoustic features. (d) shows a hypoechoic, irregular mass with angular margins and no posterior acoustic features.

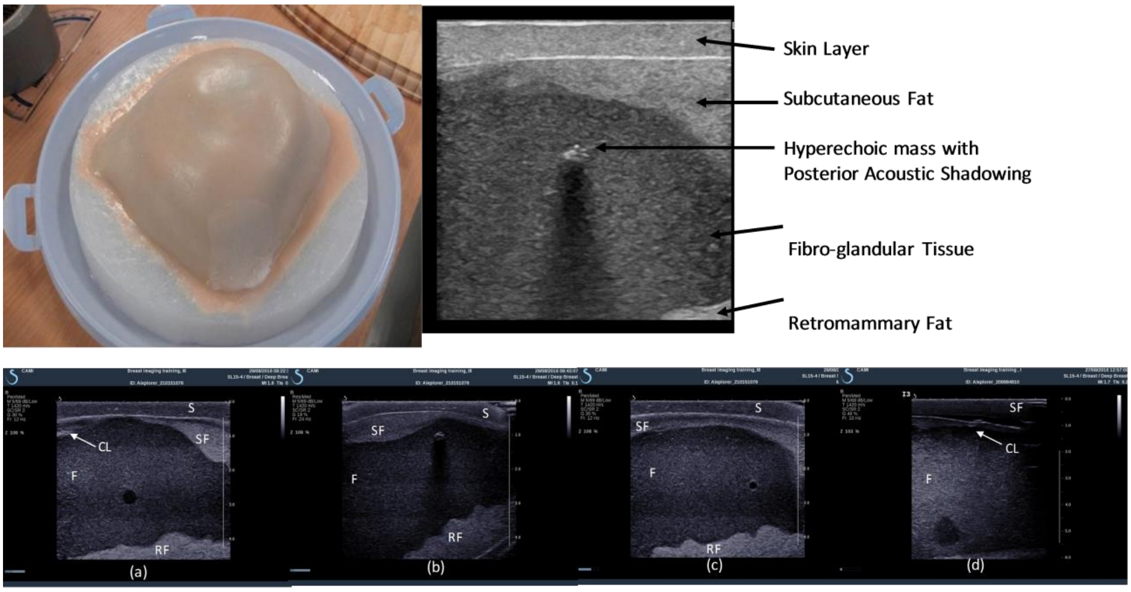

Figure 3: (a) Percentage of lesions detected pre- and post- simulation training by each of the residents'; (b) Weighted lesion characterization score pre- and post- simulation training by each of the residents; the score is weighted for the number of lesions detected and (c) Number of repeat detections of the lesions pre- and post- simulation training by each of the residents.

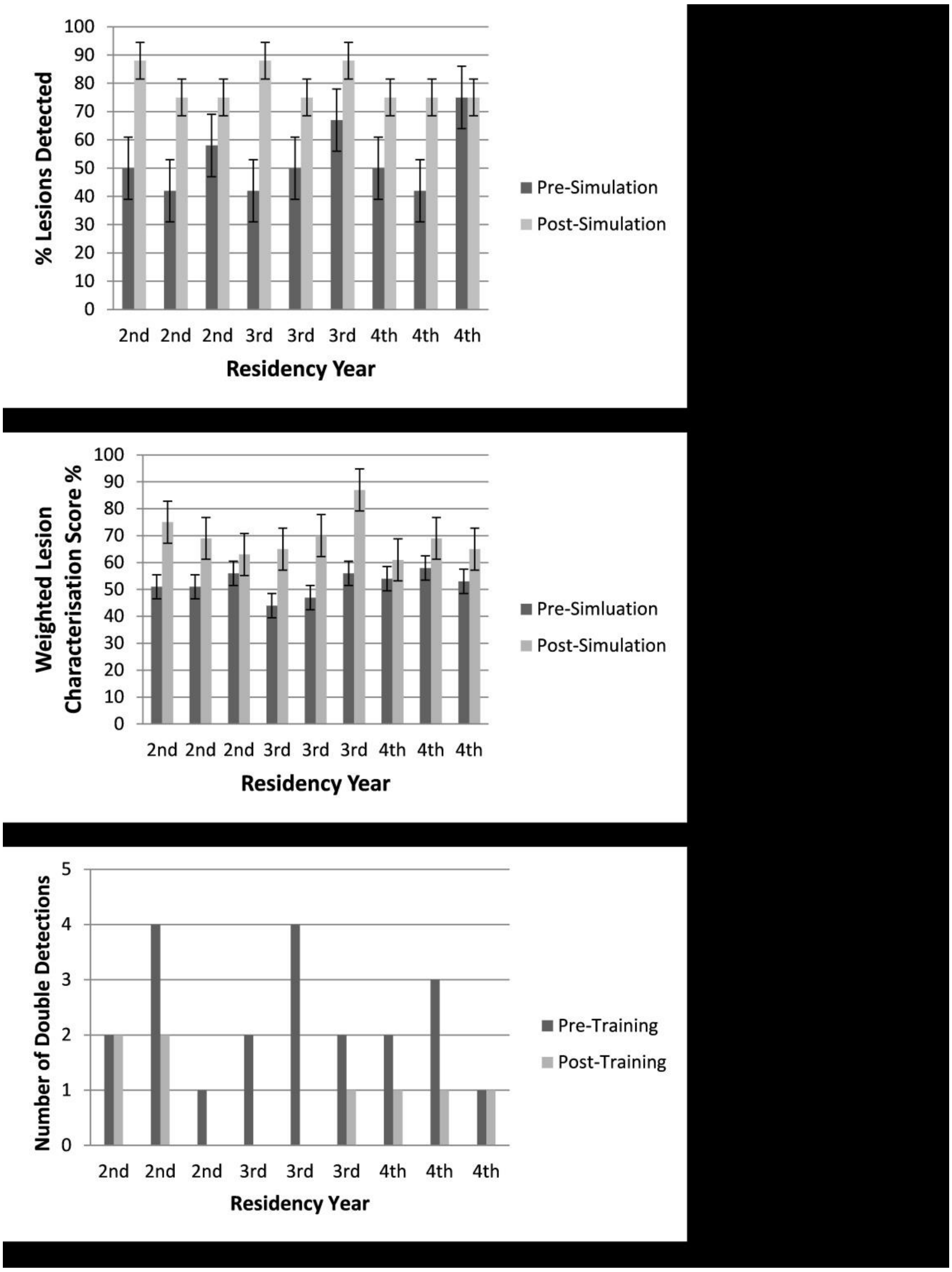

Table 1: Descriptive statistics for questionnaire summary results for exploration of association between anthropomorphic breast ultrasound training device, simulation training workshop and residents' level of confidence in performing ultrasound scans

Questions *Statements (1, strongly disagree; 5, strongly agree)*		***Mean*** *(Standard Deviation)*
(i)	The anthropomorphic breast ultrasound training device created a learning environment in which I felt comfortable.	**4.8** (0.44)
(ii)	The simulation workshop helped me to develop my confidence in the operation of an ultrasound scanner.	**4** (1.12)
(iii)	The simulation workshop helped me to develop my confidence in carrying out an ultrasound examination for example with a patient.	**4** (1)
(iv)	The simulation workshop was effective in helping me to integrate theory and practice.	**4.3** (0.71)
(v)	The anthropomorphic breast ultrasound training device produced a valuable training experience.	**4.6** (0.73)