Novel Idea

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Construction of Low-Cost Simulators for Training in Minimally Invasive Breast Procedures

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ABSTRACT

Objective: The aim of this work was to describe a technique for building low-cost simulators for training in minimally invasive breast procedures guided by ultrasound (US) and stereotactic mammography (MMG), focusing mainly on training medical professionals studying related areas.

Materials and Methods: Low-cost phantoms were developed using organic structures that mimic breast tissue, such as chicken breast and eggplant, and materials that simulate breast lesions. A step-by-step description of the preparation and use of these simulators was made, enabling the reproducibility of the technique by the physicians in training themselves.

Results: The low-cost phantoms showed a high degree of echogenic and radiological similarity with human breast tissue, allowing adequate training in minimally invasive procedures.

Conclusion: It was possible to build low-cost phantoms that allow training in US- and stereotactic MMG-guided minimally invasive breast procedures.

Keywords: Breast biopsy; tissue model; imaging phantom; training; low cost

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Key Points

- Ultrasound Phantom: Chicken breast with skin and bone was chosen to simulate breast tissue, as both have very similar ultrasound properties. Inside a chicken breast, targets were randomly inserted, varying in depth and distance between them.
- Mammographic Phantom: To build the phantom that will simulate the breast tissue in the mammography, we used: eggplants and calcium carbonate tablets to simulate calcifications/microcalcifications.
- Cost Analysis: To make the low-cost ultrasound phantom, the approximate cost was $3.45.

Introduction

Breast cancer is the type of malignant tumor that most affects women in both Brazil and worldwide, after excluding non-melanoma skin cancer. In 2022, 73,610 new cases of breast cancer were diagnosed in Brazil, which corresponds to 30.1% of all cases of cancer in the female population, of which almost 18,000 resulted in death (1).

Screening should be performed in asymptomatic women with the aim of detecting the disease early (increasing the chances of cure), improving the prognosis of the disease, and reducing morbidity and mortality. In Brazil, the National Cancer Institute recommends biannual screening mammography in women aged 50 to 69 years (2). After obtaining the images, the findings are described according to the Breast Imaging Reporting and Data System (BIRADS) classification, a nomenclature created by the American College of Radiology, with the aim of standardizing the examination report. Medical practice guidelines recommend biopsy for cases of lesions classified as BIRADS 4 and 5. Currently, needle biopsy examination is the gold standard for the diagnosis of breast cancer (3, 4), allowing for the most appropriate treatment planning for each case.

The collection of pathological material should preferably be done by needle biopsies, rather than surgical biopsies, as needle biopsies are less invasive and offer less risks to the patient. Needle biopsy techniques include fine needle aspiration biopsy, core needle biopsy (CNB) and vacuum-assisted biopsy (VAB), all of which may be guided by ultrasonography and mammography. Thus, employing needle biopsies enable the elucidation of suspected breast lesions, avoiding unnecessary surgery and aiding in the treatment planning of positive cases (5).

In order to perform a needle biopsy, whether guided by ultrasound (US) or mammography, the professional needs to position the needle inside the lesion of interest in order to obtain a representative sample. The precise spatial orientation is essential for a satisfactory specimen, avoiding delays in diagnosis and iatrogenic events (6). Therefore,

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professional training to perform breast procedures is important to improve the effectiveness of the technique, reduce professional anxiety and reduce errors and improve diagnosis and ultimately patient outcomes.

Currently, training for breast procedures can be done using phantoms, which are structures used to imitate the properties of human tissue, built with specific substances that simulate the acoustic or radiological properties of the tissue to be studied. Phantoms date from the beginning of the 20th century, but it was in the 1960s that new substitute tissues – more reliable and with a greater degree of sophistication – began to emerge (7). Currently, phantoms are manufactured using a wide variety of available raw materials and sophisticated production processes. They are important, both for carrying out scientific studies and for assessing the operating condition of devices in Medicine and Clinical Engineering. Phantoms can also be used to train health professionals in clinical applications that involve the use of US and mammography, such as when performing breast biopsies (8).

In the case of breast phantoms, inclusions are inserted to represent cysts and solid masses that simulate tumors or other abnormalities. Several studies have shown that training of professionals in breast phantoms before performing human biopsies has been very effective in increasing self-confidence when performing the procedure on real patients and significantly reducing medical errors during the process (8-13).

However, the biggest limitation of these commercialized models is their high cost, currently around 170 U.S. dollars (14), an amount that may be unfeasible for some institutions to acquire the material for students. Despite being realistic and practical models, their high cost and difficult access make this training impractical for many professionals, especially those who are at the beginning of their training. Thus, there is a need to make training more accessible to doctors in training, so that they may be able to perform a procedure with greater skill, accuracy, confidence, and safety for the patient.

Therefore, the aim of the present study was to detail the construction technique of simulators using easily accessible and low-cost materials for training in breast procedures, whether freehand or guided by US or mammography. This technique offers many advantages, such as easy accessibility of the materials, the low cost of production, similarity with the echographic and radiographic properties of the model and of the breast tissue, and reproducibility (6). Hence, it can be widely applied for the training of professionals in the field of radiology and breast imaging, in addition to other professionals involved in breast health care, especially residents. The objective was to describe a technique for building low-cost simulators for training in minimally invasive breast procedures guided by US or mammography.

Materials and Methods

Ultrasound Phantom

To build a phantom that simulates breast tissue in US, the following items were used:

- Chicken breast with skin and bone
- Stuffed olives
- Surgical gloves
- #11 Scalpel
- Water

Chicken breast with skin and bone was chosen to simulate breast tissue, as both have very similar US properties (6). Inside a chicken breast, targets were randomly inserted, varying in depth and distance. To mimic "cysts", fingers of latex or similar gloves were filled with water and tied at the end, forming small water bladders. "Solid nodules" were simulated using pitted olives stuffed with red bell pepper, thus allowing the green portion or the red portion to be defined as the target (Figure 1). Using a #11 scalpel blade, openings were made in the form of small tunnels where the targets were gently introduced (Figure 2).

After "stuffing" the chicken breast, it was placed inside a latex glove, in order to form an ovoid. (NOTE: You can also use PVC film ("clingfilm") for this purpose, wrapping the whole chicken with plastic). The fingers and cuff of the glove were tied to make the phantom easier to handle.

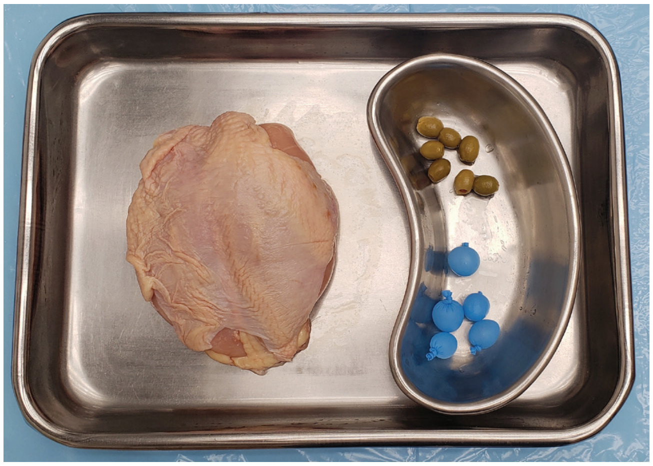

Figure 1. Chicken with skin and bone, stuffed olives, and small water bladders

Figure 2. Insertion of small water bladders to simulate cysts and stuffed olives to simulate nodules

This US phantom allows the training of:

(1) Preoperative localization with metallic guide wire;

(2) Fine needle aspiration of cysts;

(3) Fine needle aspiration of nodes/lymph nodes;

(4) CNB of nodes/lymph nodes;

(5) VAB;

(6) And clipping of non-palpable lesions.

Mammographic Phantom

To build a phantom that will simulate breast tissue in the mammography, the following items were used:

• Eggplants (aubergine);

• Calcium carbonate tablets to simulate calcifications/fine calcifications

NOTE: In addition to these materials, 2 mL of barium sulfate (Bariogel) were used to simulate a nodule for mammography. However, this may be an optional step, as in some places outside the hospital environment, this material may be difficult to access. Not using barium sulfate does not compromise the functionality of the phantom.

Similarly, to chicken breast in breast US, the composition of the eggplant also resembles breast tissue in radiographic images on mammography (10). Therefore, it was chosen to be used in the manufacture of the mammographic phantom.

To simulate calcifications and fine calcifications, crushed calcium carbonate tablets were introduced in the eggplant, and to simulate a nodule, barium gel was used. Three targets were set, arranged along the length of a raw eggplant:

• Bigger calcium particles

• Smaller calcium particles

• Barium gel

After building the phantoms, simulation of invasive breast procedures was performed using training material from the mastology outpatient clinic (Figure 3).

Aims

a) For the target "gross calcifications", a perforation was performed in the eggplant with a 12-gauge core needle, which was subsequently widened with the cap of the hypodermic needle, and the coarsely crushed calcium tablet was introduced, with the aid of a paper funnel.

b) For the "fine calcifications" target, the same previous steps were performed using the finely ground calcium tablet.

NOTE: The 12-gauge core needle and the hypodermic needle can be replaced by some other material that helps in the introduction of calcium carbonate into the eggplant, rendering them non-essential materials for the preparation of the phantom.

c) For the "nodule" target, 2 mL of barium sulfate gel was injected with a syringe (Figure 4).

This mammographic phantom allows the training of:

(1) Preoperative location;

(2) CNB;

(3) Vacuum biopsy;

(4) And clipping of lesions guided by mammography/stereotaxis, both in an alphanumeric window and on a dedicated table.

Following preparation of the phantoms and employment of the material for training procedures, they must be stored in plastic bags

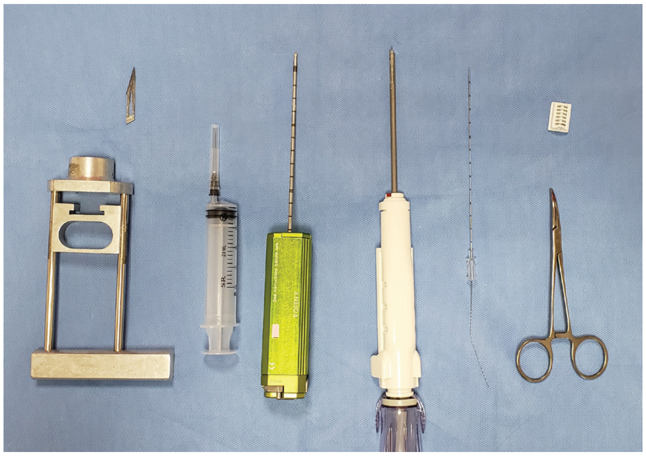

Figure 3. From left to right: cytoaspirator; #11 scalpel blade; syringe with hypodermic needle; core needle gun; vacuum biopsy device; metallic wire for preoperative localization; Hemostat, and above, a hemostatic clip

Figure 4. Introduction of 2 mL of barium sulfate (Bariogel®) into the eggplant, to simulate the nodule on the mammogram

and refrigerated (eggplant) or frozen (chicken) to be reused later. Each low-cost phantom can be reused about three times.

Cost Analysis

To make the low-cost US phantom, the approximate cost is shown in Table 1. Similarly, for the manufacture of the low-cost phantom for mammography, the approximate value is shown in Table 2.

Thus, for the manufacture of both phantoms, the approximate cost was $5.55.

NOTE: The cost of both phantoms (US and mammography) did not include the material used for the procedures (biopsy needles and needling wire)

This study was complies with the STARD Statement Checklist and following the Declaration of Helsinki.

Results

After making the breast phantoms, tests of some minimally invasive breast procedures were performed at the Diagnostic Unit of the Breast Imaging Ambulatory of the Gynecology Department, Federal University of São Paulo. Utilizing the institution's US and mammography equipment, it was possible to observe close similarities between the low-cost phantoms and real breast tissue.

For these tests on US and mammography devices, the following materials were used:

- Conductive gel for US
- LT 200 hemostatic clip

Table 1. Estimated price for making the ultrasound breast phantom for training

Materials	Approximate cost (in U.S. dollars)*
Chicken breast with skin and bone	$3
Stuffed olives	20 c (6 olives)
Surgical gloves	10 c
#11 Scalpel blade	10 c
Plastic bag	5 c
Total	**$3.45**

* Values quoted on 03/14/2023 – City of São Paulo, Brazil.

Table 2. Estimated price for making the breast phantom for training in mammography

Materials	Approximate cost (in U.S. dollars)*
Eggplant	$2
Calcium carbonate tablets	10c (2 tablets)
Total	**$2.10**

* Values quoted on 03/14/2023 – City of São Paulo, Brazil.

- Metallic wire for location of impalpable lesion (needling wire)
- Core-type biopsy needle
- Vacuum biopsy needle
- Core biopsy device (gun)
- Hemostat

Ultrasound

Contact gel was used to perform the US-guided procedures. It was possible to perform the following techniques: preoperative localization, fine needle aspiration of cysts, fine needle aspiration of nodules/lymph nodes, CNB of nodules/lymph nodes, vacuum biopsy, and clipping of non-palpable lesions (Figures 5 to 8).

Mammography

The constructed phantom has three different foci: calcifications, fine calcifications, and nodule (Figure 9). The X-ray of the eggplant phantom on the mammography equipment shows the simulated "lesions", allowing training in the following techniques: CNB,

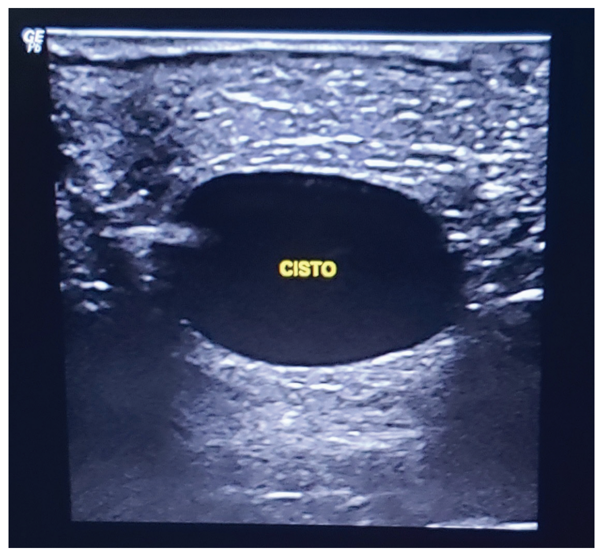

Figure 5. Appearance of the water bladder at US, very similar to a cyst

US: Ultrasound

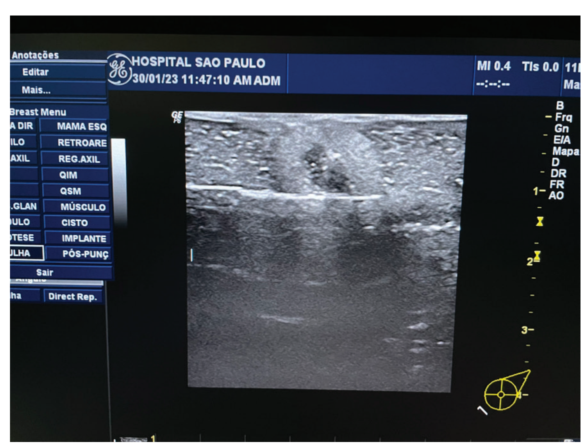

Figure 6. Tip of the core needle following piercing of the solid nodule (olive)

preoperative location, vacuum biopsy and mammography-guided lesion clipping/stereotaxis, both in alphanumeric window and in stereotactic table.

Discussion and Conclusion

Percutaneous techniques guided by US and mammography are basic procedures in radiological practice when imaging the breast. However, many residents graduate without a minimum of technical experience (12).

Several studies have shown that training on synthetic simulators increases the self-confidence of the training professional and reduces medical errors during the procedure (8-13). An ideal phantom should combine cost-benefit, availability, and similarity to the target organ/tissue (13). In terms of the synthetic breast simulators sold on the market, the biggest obstacles are their high cost and difficult access, making it difficult to practice the technique of minimally invasive breast procedures.

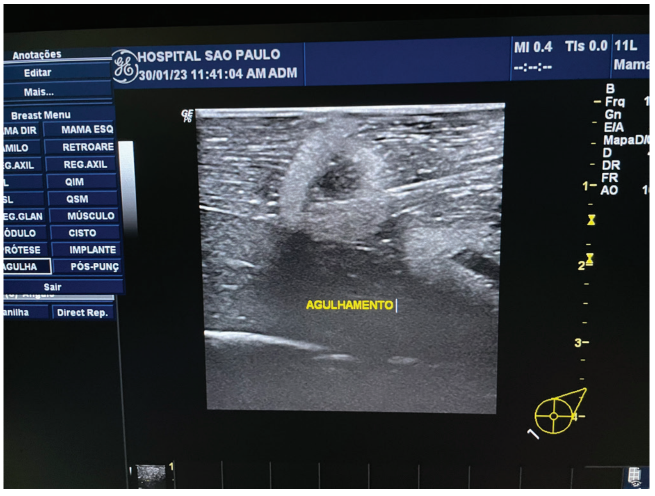

Figure 7. Detail of the metallic wire crossing the target lesion

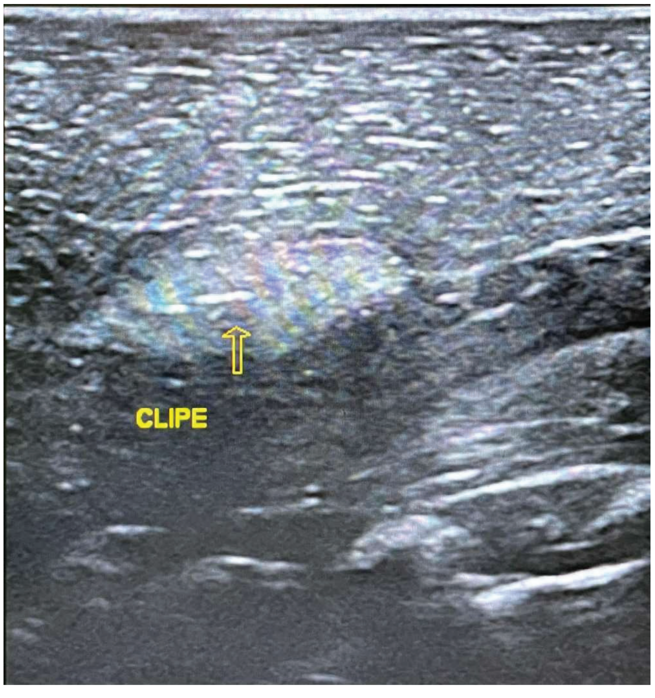

Figure 8. Location of the clip inside the olive on US

US: Ultrasound

Therefore, we describe the technique for the construction of low-cost phantoms, similar to breast tissue, and using easily accessible materials, in order to enable their easy replication. With these phantoms, it is possible to carry out the training in the main procedures in breast imaging, with an effectiveness similar to the procedure performed in patients.

The total cost for manufacturing both the phantoms described was around USD $5.55, or about 97% cheaper than the synthetic phantom available on the market (14).

Comparatively, the images obtained by the ultrasonic and mammographic phantoms resemble those of a real breast. On US, the simple cyst simulated by the phantom appears anechoic, well circumscribed, with thin walls, with liquid inside and posterior reinforcement, just like a simple cyst in a real breast (Figures 10 and 11). The "simple nodule" in the phantom, represented by the stuffed olive, appears circumscribed, with an oval shape and well-defined margins. It is possible to differentiate the olive from the filling by echogenicity, with the olive being more hyperechogenic and the filling being more hypoechogenic. In this way, it is possible to biopsy different portions of the "nodule". Similarly, to the phantom, the solid breast nodule may also appear with circumscribed margins and an oval shape (Figures 12 and 13). The echogenicity and shape of an actual nodule can vary according to the nodule composition.

On mammography, calcifications are always radiopaque. In the mammographic phantom, the "calcifications" displayed in a very similar aspect, sometimes coarse (depending on the size of the ground particles) as in a real breast (Figure 14).

The phantom "nodule" also appears hyperdense, like a suspected lesion, due to the insertion of barium sulfate. Note the similarity with the image of a nodule in a real breast (Figure 15).

We believe that these low-cost phantoms can be used for training professionals in the field of mastology, as the characteristics of the selected materials are extremely similar to real breast tissue and breast lesions.

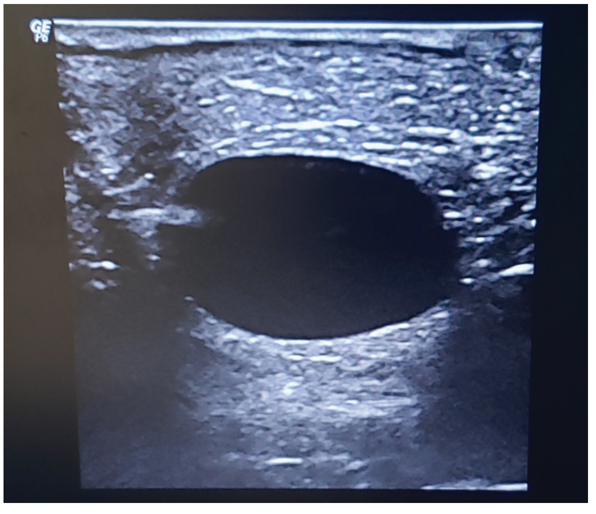

Figure 9. Mammographic image of eggplant with simulated lesions: calcification, fine calcification and nodule

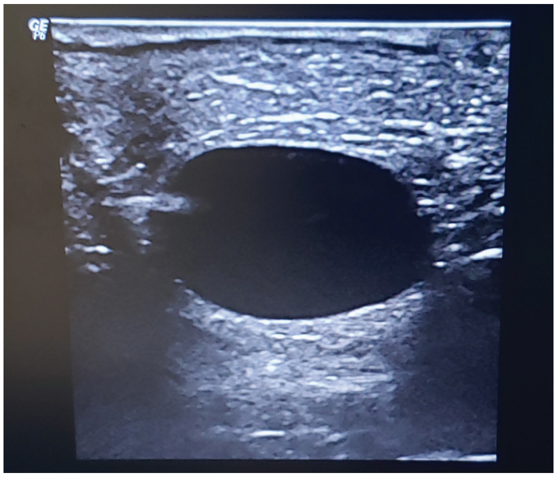

Figure 10. Simple cyst seen on US in the Phantom

US: Ultrasound

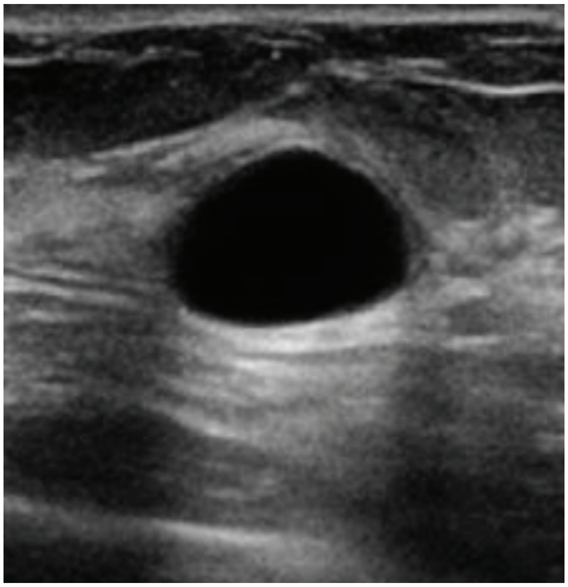

Figure 11. Simple cyst seen on US in the breast

US: Ultrasound

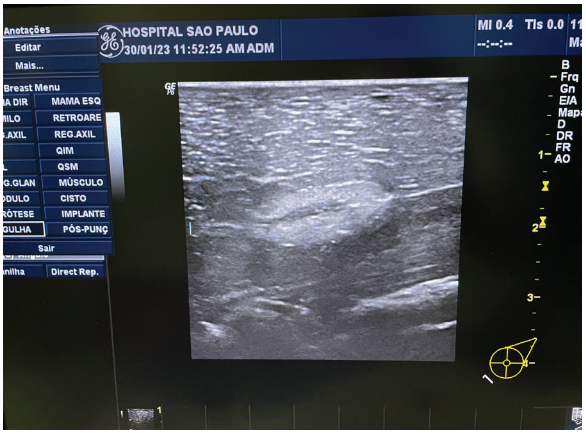

Figure 12. Solid nodule identified on US in the Phantom – note the similarity between the phantom image and on the real breast (Figure 14)

US: Ultrasound

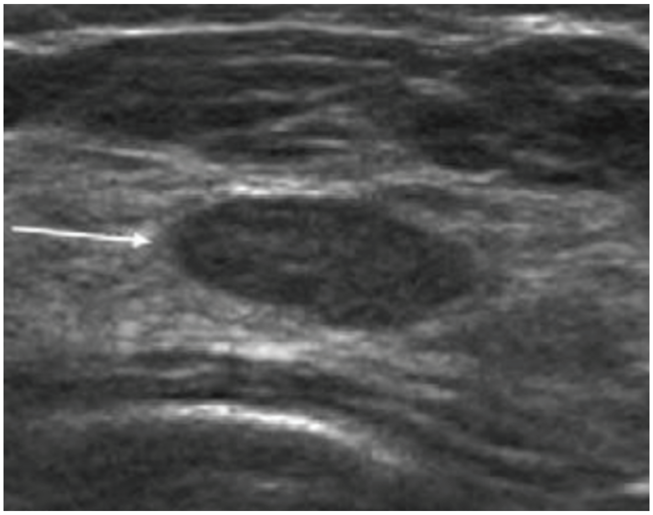

Figure 13. Solid nodule identified on US in the real breast

US: Ultrasound

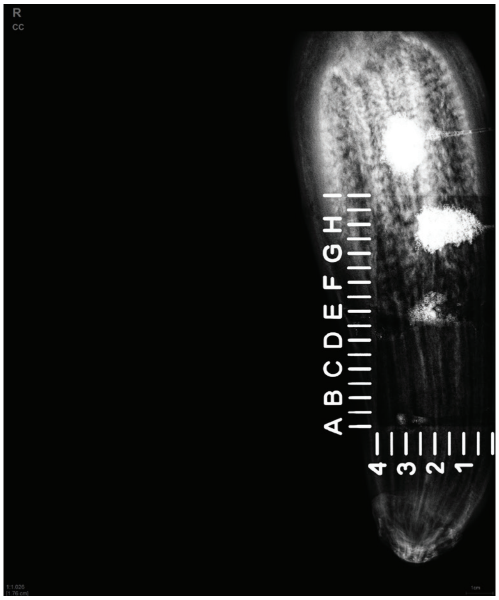

Figure 14. Calcifications seen on mammography in the Phantom

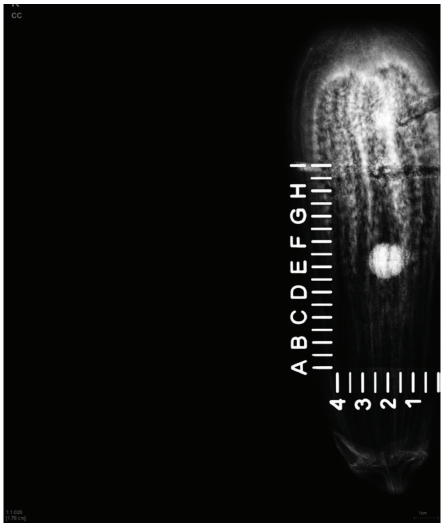

Figure 15. Nodule seen on mammography in the Phantom

The developed simulators used simple and easily accessible materials for manufacture, having an excellent cost-benefit ratio. Furthermore, they show great echographic and radiographic similarity with the real breast and associated lesions. Thus, these low-cost phantoms can be used to train professionals in the performance of invasive procedures in the field of breast imaging, enabling them to acquire self-confidence, experience, and mastery of the technique before performing *in vivo* procedures.

Ethics Committee Approval: This study was reported according to the STARD Statement Checklist and following the Declaration of Helsinki.

Informed Consent: Not necessary.

Peer-review: Externally peer-reviewed.

Authorship Contributions

Surgical and Medical Practices: M.K.C., M.A., R.D.S.S., S.E.; Concept: M.K.C., S.E.; Design: M.K.C., S.E.; Data Collection and/or Processing: M.K.C., S.E.; Analysis and/or Interpretation: M.K.C., R.D.S.S., S.E.; Literature Search: M.K.C., M.A., R.D.S.S., S.E.; Writing: M.K.C., M.A., S.E.

Conflict of Interest: The authors have no conflicts of interest to declare.

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