Value of artisanal simulators to train veterinary students in performing invasive ultrasound-guided procedures

Maria Cristina F. N. S. Hage, Ana Beatriz Massaferro, Érika Rondon Lopes, Carolina Mariano Beraldo, and Jéssika Daniel

Department of Veterinary Medicine, Faculty of Animal Sciences and Food Engineering, University of São Paulo, Pirassununga, São Paulo, Brazil; and Tenente Aviador Gustavo Klug Technical School, Pirassununga, São Paulo, Brazil

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Percardial effusion consists of liquid accumulation within the pericardium. Percardial effusion is common in large dogs and results in serious damage, endangering the life of the animal. The main causes of pericardial effusion are congestive heart failure, hypalbminemia, peritoneopericardial hernia, infectious pericarditis of bacterial origin (e.g., actinomycosis, nocardiosis, and tuberculosis), fungal (coccidioides), hemorrhage (hemopericardium), iatrogenic or external trauma, and cardiac rupture (particularly of the left atrium) (4).

Cardiac tamponade develops when the intrapericardial fluid becomes high and compresses the heart, leading to low cardiac output and congestive heart failure (4).

Ultrasound-guided pericardiocentesis is an important procedure for pericardial effusion because it removes abnormal fluid. The procedure is simple but requires expertise because it is commonly performed in emergency care in unexpected circumstances. Using ultrasound, fluid accumulation can be visualized in the pericardium, which facilitates the introduction of the catheter and fluid suction. This procedure requires caution; the catheter must not touch the heart because it may cause cardiac arrhythmias. Therefore, cardiac and ultrasound monitoring can prevent risks (4).

The development of technical expertise in medical procedures is extremely important for acute and critical care physicians. However, opportunities to gain experience in critical procedures to save lives during emergencies care is rare and depends on chance (8).

The Society for Academic Emergency Medicine recommends that simulators be used for ultrasound-guided training procedures.

Realism is a key factor for a medical simulator to be suitable for training professionals (6). Thus, phantoms of varying costs have been developed.

Expensive phantoms involve cutting-edge technology, for example, the virtual simulators used for training needle biopsy of thyroid gland nodules (6). The use of virtual reality allows the learner to repeatedly explore the structures of interest, prepare them apart, join them together, and visualize them from almost every perspective. The greatest advantage of this medical procedure training method is the ability to manipulate a virtual environment; therefore, the physician can perform the procedure repeatedly without any harm to the patient.

Additionally, there is the Blue Phantom, which is used in human medicine. The Blue Phantom is a realistic and durable simulator that features various scenarios for interventional training of the sonographer, mimicking paracentesis, renal biopsy, thoracentesis, pericardiocentesis, vascular access, and other procedures.

A Blue Phantom for ultrasound-guided pericardiocentesis costs about US$ 40,000.00. Another commercial phantom for ultrasound-guided pericardiocentesis, the Kyoto Kagatu, costs about US$ 2,980.00. Because the cost of these phantoms is a limitation for universities in the developing countries looking to acquire them, artisanal simulators have been developed as a cheaper alternative.

In an attempt to train and improve professionals for ultrasound use in vascular access procedures, a low-cost model with easy preparation and excellent applicability was developed. The materials used were simple, including a piece of thawed chicken breast, expired prosthetic tubes, suture thread, and a hydrophilic sphere used in plant ornamentation (5).

Previous researchers developed a pericardiocentesis model with cheap materials and concluded that it could be used as an ultrasound-guided pericardiocentesis training model for the emergency care of human patients. This model has been...
offered in graduate programs in emergency ultrasound for life support to physicians of all specialties in Germany, Austria, and Switzerland (2).

In veterinary medicine, there are similar limitations for suitable training of students. Pericardial effusion with cardiac tamponade and pleural effusion with respiratory stress are some of the conditions that require training (7). The present study is aimed at testing and adapting models that can be made at home for ultrasound-guided pericardiocentesis training.

MATERIALS AND METHODS

Model development. Multiple models were evaluated by the work team and tested until the model that most closely approached the reality was found, based on the overseeing instructor’s experience and the literature.

The chosen model was composed of opaque plastic pots (6.69 in. long, 5.12 in. wide, and 3.15 in. deep) filled with unflavored gelatin (24 g gelatin diluted in 400 ml water). Before gelatin solidification, two 7-in. balloons, each containing a chicken heart and diluted red gouache ink (100 ml water/20 ml ink), were immersed. After gelatin solidification in the refrigerator, the model was covered with a silicone rubber band (elastic band used for gymnastics) to mimic the skin and to avoid content visualization by the participant (Fig. 1).

The materials used for the development and manufacturing of the model cost approximately US$ 163.82, and the preparation was completed within 24 h. The specific materials and their prices are shown in Table 1.

Ultrasound equipment. The My Lab Class C Vet (Esaote) ultrasound was used with a 6.0- to 18.0-MHz electronic linear transducer (LA435).

Participants. Participants were divided into two groups: veterinary professionals and veterinary students. The veterinary professional group (18 participants) consisted of two graduates, six residents (R1), five MSc students, three PhD students, one PhD, and one postdoctoral fellow; none had performed a pericardiocentesis before. The group of veterinary students consisted of 36 undergraduate students who had completed coursework in diagnostic imaging, and none of them had performed a pericardiocentesis before.

Procedure performed by the participants. Participants were introduced to the model in pairs and were shown a film of a dog with pericardial effusion on the ultrasound device. The pericardial sac, pericardial effusion, heartbeat, and electrocardiographic tracing were demonstrated (Fig. 2, A and B).

After the demonstration, the problems related to cardiac tamponade, the difficulty of dilating the cardiac chambers due to the surrounding liquid under pressure, and the consequent decrease of blood flow into the heart each diastole, leading to low cardiac output after systole, were briefly explained. Thus, the urgency needed to alleviate external pressure on the heart through pericardiocentesis was described.

The need to further investigate the causes of fluid accumulation (e.g., through pericardial fluid analysis) postpericardiocentesis was emphasized.

The second step was to demonstrate the pericardiocentesis procedure and equipment assembly. The syringe, extensor tube, and catheter connector were attached to the three-way tap, and participants learned how to introduce the catheter into the pericardium through the skin and chest muscles after asepsis with alcohol and how to remove the needle and leave the silicone part in the pericardium (Fig. 3, A and B).
The three-way tap manipulation and aspiration technique were then mimicked using two plastic cups and water. The aspirated liquid was discarded in a closed system. First, the tap was opened between the pericardium, and the syringe and closed between the syringe and the disposal while the pericardial fluid was aspirated; the tap was then closed to the pericardium and opened between the syringe and disposal to send the pericardial fluid into the collection container. Afterward, the instructor explained that, in a real situation, the catheter should not touch the heart to avoid premature ventricular complexes in the electrocardiogram. In a real situation, the animal must be maintained with cardiac monitoring. If a premature ventricular complex occurs, the catheter should be recoiled.

Participants were placed on each side of the examination table around the model. One participant was responsible for finding the pericardium and heart in the gelatin pot through ultrasonography (Fig. 3, C and D), and the other participant was responsible for assembling the apparatus and performing the aspiration. The participant who guided the ultrasound also held the catheter. Once the task was completed, the participants changed places and performed the same procedure (each model contained two sets of pericardia and hearts; Fig. 2, C and D).

Questionnaire. After all the procedures, participants filled out a questionnaire. The questionnaire was developed based on the literature and had open- and closed-ended questions (1). The closed-ended questions were prepared using a visual analog scale. The participant was asked to mark an X over a 10-cm line that best represented his or her answer. On each end of the scale, keywords described the extreme values of the evaluated item. The questionnaire was formulated using simple words that were free of double meaning to find accurate and honest answers. To make the visual analog scale easier to understand, an example was provided on the questionnaire cover. The score of each question was obtained by measuring the line from the beginning until the X marked by the participant.

The questionnaire was administered to study participants after the ultrasonographic evaluation of the model.

Statistical analysis. Participants were divided into two groups: veterinary professionals and veterinary students who had completed diagnostic imaging coursework. For each group, questions 1–9 were scored, and the scores were tabulated and analyzed with the free Graph Pad Prism 5 Demo program to generate a box-and-whisker plot type graph (3). Characteristics with scores below four were defined as strong points of the model, and characteristics with scores above four

<table>
<thead>
<tr>
<th>Item Used</th>
<th>Unit Price, US$</th>
<th>Quantity</th>
<th>Total Price, US$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balloons (package of 50 units), size:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 in. (7.09 in.)</td>
<td>18.92</td>
<td>1</td>
<td>18.92</td>
</tr>
<tr>
<td>Catheter (20 gauge)</td>
<td>4.65</td>
<td>1</td>
<td>4.65</td>
</tr>
<tr>
<td>Disposable cup (package of 50 units)</td>
<td>17.99</td>
<td>1</td>
<td>17.99</td>
</tr>
<tr>
<td>Chicken heart, 2.20 lb</td>
<td>63.08</td>
<td>1</td>
<td>63.08</td>
</tr>
<tr>
<td>Two-way catheter connector</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>macrodrops</td>
<td>7.43</td>
<td>1</td>
<td>7.43</td>
</tr>
<tr>
<td>Extension tube</td>
<td>3.98</td>
<td>1</td>
<td>3.98</td>
</tr>
<tr>
<td>Gelatin</td>
<td>13.84</td>
<td>2</td>
<td>27.68</td>
</tr>
<tr>
<td>Recycled ice cream pot</td>
<td>0.83</td>
<td>1</td>
<td>0.83</td>
</tr>
<tr>
<td>Syringe (5 ml)</td>
<td>14.94</td>
<td>1</td>
<td>14.94</td>
</tr>
<tr>
<td>Red gouache ink (100 ml)</td>
<td>4.32</td>
<td>1</td>
<td>4.32</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>163.82</td>
</tr>
</tbody>
</table>

Table 1. Price table of the materials used to manufacture the proposed pericardial effusion model

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Fig. 2. A and B: ultrasound images of a real pericardial effusion in a dog. The pericardium, pericardial effusion, heart, and electrocardiogram tracing were observed. C and D: ultrasound images of the experimental model. Note the wall of the balloon mimicking the pericardium, the ink gouache mimicking pericardial effusion, and the chicken heart mimicking the dog heart. In D, the balloon wall retracted after ink gouache aspiration.
were defined as weak points. The open-ended questions were analyzed by percentage.

RESULTS

Each model took an average of 20 min to prepare before going into the refrigerator. The experimental model with two balloons in each pot was used by two participants and then discarded.

The answers for questions 1–9 of the veterinary professional group were tabulated, and a box-and-whisker plot type graph was generated (Fig. 4).

The answers for questions 10–13 were analyzed by percentage. Eighteen professionals (100%) reported that the experience with the model helped them prepare for a real situation. Twelve professionals (67%) concluded that the task was easy, and six professionals (33%) described the task as difficult. Sixteen professionals (89%) said that two people were enough to perform the fictitious pericardiocentesis, whereas two professionals (11%) requested an auxiliary participant. Five professionals (28%) suggested that the heart should beat, one professional (5%) suggested that the ink used for pleural effusion should be different from the blood inside the heart, one professional (5%) suggested improving catheter visualization, and eleven professionals (62%) had no additional comments.

The answers for questions 1–9 of the veterinary study group were tabulated, and a box-and-whisker plot type graph was generated (Fig. 5).

The answers for questions 10–13 were analyzed by percentage. Thirty-six students (100%) reported that the experience with the model helped them prepare for a real situation. Twenty-four students (66.6%) concluded that the task was easy, eleven students (30.5%) described the task as difficult, and one student (2.9%) found the task reasonable. Thirty-six students (100%) said that two people were enough to perform the fictitious pericardiocentesis. Twelve students (33%) suggested that the fictitious skin should be more adhered to the gelatin. Three students (8%) suggested that the heart should beat, two students (5.4%) suggested the existence of ribs and blood vessels, two students (5.4%) suggested that the container should be larger to improve manipulation, two students (5.4%) suggested that the container should be larger and have more skin adherence, one student (2.5%) suggested the existence of ribs, muscles, and pleura, and one student (2.5%) suggested that the heart should beat and that there be better visualization.
We agree that the model was weak for surrounding tissues visualization because only a low echogenicity material (the gelatin) was visualized in the model, whereas air within the lungs causes reverberation artifacts in real animals. Participants complained of some difficulty in puncturing the pericardium (balloon) that may have been caused by reuse of the same catheter several times. Visualization of the catheter inside the model was difficult for many participants. This finding should actually not be interpreted as a weakness of our model because visualization is not always possible in a real procedure. The catheter is kept away from the heart based on the reduction of fluid in the pericardium and the electrocardiographic findings (premature ventricular complexes) if the catheter had touched the heart, rather than based on the visualization of the catheter.

Veterinary professionals classified the realism of the experimental heart as moderate and undergraduate students classified it as strong. The chicken heart mimicked the four heart chambers of the dog very well, but it did not move. The size of the heart in our model, which was smaller than a dog’s heart, caused no hindrance because the ultrasound device enabled image magnification without loss of definition.

In the discursive questions, all participants, both undergraduate students and professionals, felt that this experience with the model helped prepare them for a future real situation. The most common suggestions were related to the absence of a heartbeat and the fictitious skin being too loosely attached to the gelatin.

Therefore, we conclude that the participants’ responses are positive for training using this useful experimental model.

Comparing our model with the other model previously proposed (2), we can yet emphasize some strengths. While the other authors (2) found that their model was regarded as not realistic by most participants and the decrease in fluid could not be followed well, our model was considered realistic by most participants and the decrease in fluid could be easily monitored. Otherwise, in both models, we noticed that they were weak in simulate the surrounding tissue, i.e., the gelatin did not simulate well the air within the lungs producing the pattern reverberation artifact.

We agree with Wang et al. (8) in that simulation provides an intentional practice opportunity to develop technical psychomotor skills that can be performed without pressure.

We believe that the participants acquired confidence to perform the procedure because they were in a controlled environment and had no pressure. However, we do not believe that a single exposure to the model is enough to acquire the

### Table 2. Strengths and weaknesses of the model according to the professionals and undergraduate students

<table>
<thead>
<tr>
<th>Item Evaluated</th>
<th>Professionals</th>
<th>Undergraduate Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Pericardial visualization</td>
<td>Strong</td>
<td>Strong</td>
</tr>
<tr>
<td>2. Heart visualization</td>
<td>Strong</td>
<td>Strong</td>
</tr>
<tr>
<td>3. Pericardial fluid visualization</td>
<td>Strong</td>
<td>Strong</td>
</tr>
<tr>
<td>4. Surrounding tissue visualization</td>
<td>Weak</td>
<td>Moderate</td>
</tr>
<tr>
<td>5. Pericardial puncture</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>6. Catheter visualization</td>
<td>Weak</td>
<td>Weak</td>
</tr>
<tr>
<td>7. Fluid decrease visualization during the fictitious pericardiocentesis</td>
<td>Strong</td>
<td>Strong</td>
</tr>
<tr>
<td>8. Realism of the experimental heart</td>
<td>Moderate</td>
<td>Strong</td>
</tr>
<tr>
<td>9. Realism of the phantom</td>
<td>Strong</td>
<td>Strong</td>
</tr>
</tbody>
</table>

Fig. 5. Box-and-whisker plot demonstrating the minimum value, 25th percentile value (first quartile), median, 75th percentile (third quartile), and maximum value measured on the VAS of questions 1–9 for the undergraduate student group. Characteristics with scores below four were defined as strong points of the model, and characteristics with scores above four were defined as weak points.
expertise needed to perform a real pericardiocentesis. A greater number of exposures to the model and real pericardiocentesis monitoring may give the veterinarian a greater sense of security during a real procedure.

The technique execution also depends on personal characteristics: daring or apprehensive. These characteristics can be used when selecting staff to work in emergency situations. Daring people will possess the inherent skills needed for such occasions, after adequate training.

In human medicine (e.g., in the Radiology Institute at University of São Paulo Clinical Hospital), the doctor in training must perform 10 fine-needle aspirations in breasts to be considered fit to perform a fine-needle aspiration in the thyroid because the risk of damaging important neck vessels is greater (6).

We have not yet estimated risk for pericardiocentesis, but we understand that it is a procedure that requires caution to perform. Pericardiocentesis is uncommon in our hospital routine; therefore, we intend to demonstrate to the students how to proceed in such situations. Otherwise, they would become professionals without this valuable experience aimed to save lives.

The course of the project was very interesting because, while the participants could have found the model childish, everyone was actually delighted with the opportunity to handle the ultrasound transducer and perform a pericardiocentesis. The development of this project was a very rewarding experience for our team, and its wide acceptance encourages us to further develop models.

Besides the fact that the cost advantage that was tremendous when you compare US$ 40,000.00 for the Blue Phantom or US$ 2,980.00 for the Kyoto Kagatu with the US$ 163.82 of our model, teachers can propose it to be made at home by the students and bring to train at the veterinary school, making the activity even more ludic and proactive.

The pericardial effusion leads to compression of the heart, leading to a reduction of its filling (reduction of preload), which consequently reduces blood flow for the body (low cardiac output). This phenomenon leads to signs of weakness and collapse due to the small amount of circulating oxygenated blood (4). Thus, the importance of learning this technique to save lives is clear. The opportunity of training in cheap phantoms can move forward the education experience of students of veterinary and human medicine, consolidating basic concepts of cardiac physiology and pathophysiology.

In conclusion, this simulation supplies our need for a practical and cost-effective model for ultrasound-guided pericardiocentesis training.

GRANTS

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DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

AUTHOR CONTRIBUTIONS

Author contributions: M.C.F.N.S.H. conception and design of research; M.C.F.N.S.H., A.B.M., E.R.L., C.M.B., and J.D. performed experiments; M.C.F.N.S.H. and A.B.M. analyzed data; M.C.F.N.S.H. and A.B.M. interpreted results of experiments; M.C.F.N.S.H. and A.B.M. prepared figures; M.C.F.N.S.H. and A.B.M. drafted manuscript; M.C.F.N.S.H. and E.R.L. edited and revised manuscript; M.C.F.N.S.H., A.B.M., E.R.L., C.M.B., and J.D. approved final version of manuscript.

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