A low-cost system for image-guided computer-navigated pericardiocentesis training

V. Harish[1*], A. Baksh[1*], T. Ungi[1], R. Pal[2], G. Fichtinger[1]
*V. Harish and A. Baksh are joint first authors
[1] Laboratory for Percutaneous Surgery, Queen's University, Kingston, Canada
[2] Department of Cardiology, Queen's University, Kingston, Canada

Keywords: Medical Training, Phantom, Ultrasound, Pericardiocentesis

Purpose: Canadian medical universities are in the process of transitioning to a Competency-Based Medical Education (CBME) model at all levels of training. Achievement of competence requires practice, and for reasons of patient safety and trainee comfort, the early stages of practice are best done in a simulated environment [1]. Phantoms simulating human anatomy have been created to objectively evaluate trainees in a variety of medical procedures.

Pericardiocentesis is a relatively rare, but high-risk procedure that involves the aspiration of fluid from the pericardial cavity to relieve compression of the heart. The current standard of care involves the use of ultrasound imaging to provide real-time visualization of the needletip in relation to surrounding organs [2]. Commercially available pericardiocentesis phantoms, such as Blue Phantom's Transthoracic Echocardiography and Pericardiocentesis Ultrasound Training model (CAE Healthcare Canada, QC, Canada), are extremely expensive (http://www.bluephantom.com). Inexpensive phantoms have common limitations such as the lack of realistic anatomical landmarks and the inability to pump [3, 4]. Thus, our goal was to create a low-cost, realistic phantom that could be used alongside an open-source software platform for image-guided pericardiocentesis intervention training.

Methods: Our pericardiocentesis phantom consists of a heart model within a plastic container filled with gelatin. To construct the heart model, one balloon is placed inside a second balloon with pneumatic tubing running out of the inner balloon. This tubing is connected to a 60 cc syringe used to simulate pumping. Each balloon is filled with water of a different color, allowing users to easily determine if they are draining the pericardial effusion or have punctured the heart. The heart model was placed in a container filled with gelatin with the pneumatic tubing running out of the top of the container. Plastic cutting board was cut to look like the sternum and ribs and was placed on top of the gelatin. Silicon skin was placed on top of the ribs. The cost for the first phantom is roughly $10, however as the container, tubing, cutting board, and silicon skin are reusable, the costs decrease further as more phantoms are built. Five phantoms can be prepared under an hour without taking into account the time needed for the gelatin to set in the refrigerator.

The Sonix Touch cart ultrasound machine (Analogic Corp., Peabody, MA, USA) with the 3D Guidance trakSTAR electromagnetic tracking system (Northern Digital Inc., ON, Canada) were used while testing the phantom. A reference sensor was placed underneath the phantom and a tracked needle was used to drain the effusion (Fig.1). The electromagnetic tracker was connected to a computer running the PLUS software toolkit's PlusServer application (https://www.assembla.com/spaces/plus/wiki). PlusServer relayed all tracking and image data to 3D Slicer, a commonly used open-source platform for image-guided interventions (http://www.slicer.org/). Using basic features of SlicerIGT (http://www.slicerigt.org/wp/), an extension for 3D Slicer, models representing the needle tip were created and visualized relative to the ultrasound image plane. The tip of the needle was marked with a sphere, allowing users to distinguish between the tip of the needle and the needle shaft (Fig 2).

Results: Our system allows for trainees to practice ultrasound-navigated pericardiocentesis at very low costs. Our phantoms appear sonographically and anatomically realistic. The syringe can be pumped to create a beating effect at 30 beats per minute. Exploring a different pumping mechanism as opposed to manually pumping a syringe may allow us to have a more rapid beating effect. The difference between the filled and unfilled inner balloon is clearly visible under ultrasound, as once the inner balloon is filled it appears hyperechogenic to the water in the outer balloon representing the pericardial effusion (Fig. 2).

The two balloon layers appear similar to the pericardium and myocardium, decompression of the myocardium is clearly visible in the ultrasound, and the synthetic ribs and skin provide realistic anatomical landmarks. The amount of water in the inner and outer balloon can also be changed easily, allowing us to create heart models of various sizes—representing males and females with different sized effusions. Visualizing the tip of the needle aids during the training process since it is easy to mistake the shaft of the needle for the needletip, causing trainees to drive the needle too far and puncture the heart. Our phantom, if refrigerated, can last about a week; however, they are single-use. Five phantoms were created, appearing identical except for the amount of water placed in the outer balloon to simulate different difficulties for the procedure. Needle insertion trials were attempted on each of these phantoms by unskilled, non-clinical students. Three out of the five trials were unsuccessful due to inexperience of the students, however there was no mechanical failure of the phantoms.

Conclusion: We have created a phantom for pericardiocentesis training using inexpensive materials and demonstrated it with an open-source navigation software in ultrasound-guided pericardiocentesis interventions. Owing to its low cost and manufacturing complexity, the phantom is easily reproducible; and in conjunction with an open source navigation system, it promises to be a viable tool in training residents to perform pericardiocentesis before they are expected to perform it on patients. Future work will involve user-performance studies and adding self-sealing capability to the phantom, allowing it to be used multiple times.

References:
[1] Wang, E. E., *et al*. (2008). Developing Technical Expertise in Emergency Medicine—The Role of Simulation in Procedural Skill Acquisition. *Academic Emergency Medicine*, 15(11), 1046–1057. [2] Loukas, M., *et al*. (2012). Pericardiocentesis: A clinical anatomy review. *Clinical Anatomy*, 25(7), 872–881. [3] Campo Dell'orto, M.C., *et al*. (2013). Assessment of a Low-Cost Ultrasound Pericardiocentesis Model. *Emergency Medicine International*, 2013, n.p. [4] Zerth, M., *et al.* (2012, Dec). An Inexpensive, Easily Constructed, Reusable Task Trainer for Simulating Ultrasound-Guided Pericardiocentesis. *The Journal of Emergency Medicine,* 43(6), 1066-1069.

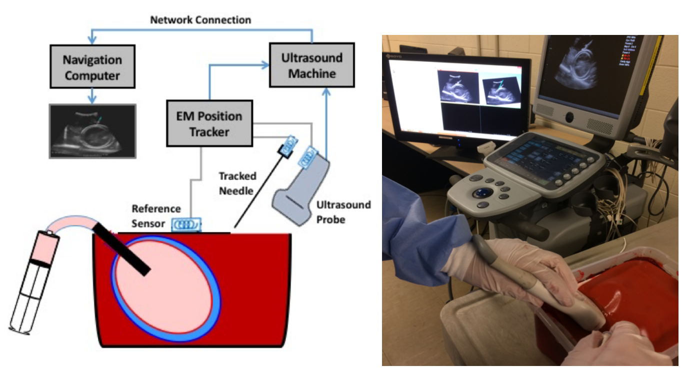

Fig 1. *Schematic diagram (left) and photograph (right) for performing ultrasound image-guided, pericardiocentesis on low-cost phantoms.*

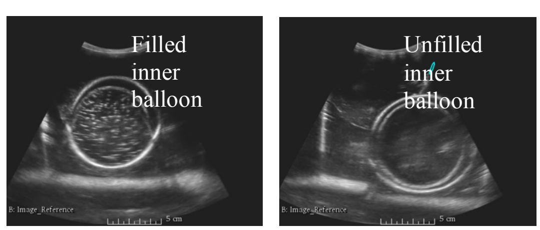

Fig 2. *Ultrasound images of a phantom with a filled (left) and unfilled inner balloon showing use of SlicerIGT to visualize the needle during insertion (right).*