CARDIAC ULTRASOUND PHANTOM USING A PORCINE HEART MODEL

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Abstract—A beating cardiac phantom has been developed using an excised porcine heart for use as a training tool in echocardiography. The heart is fixed with a formalin-based preservation method, housed in an optically transparent Lexan chamber, and undergoes hydraulic pumping to circulate a blood-mimicking fluid. The cardiac phantom has been used for a period of four months to produce images of excellent quality with ventricular wall motion typical of human subjects.

Key Words: Echocardiography, Phantom.

INTRODUCTION

We have previously described anthropomorphic cardiac phantoms for training in echocardiography as well as equipment validation for cardiac ultrasound scanners (Smith and Rinaldi 1989a, 1989b; Smith et al. 1994). To simulate the heart, we used flexible polymer left ventricles including coronary arteries (Smith et al. 1991) and containing mechanical tilting disk prosthetic heart valves at the mitral and aortic ports. The ventricle is housed in an optically transparent Lexan chamber. Three orthogonal membrane windows mounted in the viewing chamber walls and an esophageal port enable ultrasonic imaging/Doppler examinations of the left ventricle and prosthetic valves from the four conventional clinical cardiac ultrasound views, i.e., long axis, short axis, apical and transesophageal imaging.

The ventricle is connected to a reservoir and mock circulatory system. A variable speed piston pump driven by a DC motor is connected to the cavity/chamber by a single port. Thus, as the degassed water is pumped in and out of the cavity/chamber, the left ventricle is forced to pump the blood medium through the circulatory loop.

Notwithstanding these features, the phantom is still a crude approximation to human cardiac anatomy.

An excised animal heart would be a more accurate model if problems of flexibility during hydraulic pumping and long-term storage could be solved. Excised porcine kidney phantoms have been previously described for ultrasound hyperthermia (Benkeser et al. 1990; Holmes et al. 1984) and diagnosis (Fowlkes et al. 1994) using ethanol fixation. However, our attempts to extend these preservation techniques to obtain a flexible, cardiac phantom were not successful and produced only a rigid heart.

In this paper, we describe the development of a new beating porcine heart tissue model for training applications and equipment validation in echocardiography. The mechanical design of the phantom is identical to our previous model (Smith and Rinaldi 1989a). Here, we include the preservation technique and long-term evaluation using ultrasound scanning.

METHODS

This study involving experimental animals was approved by the Duke University Institute for Animal Care and Use Committee. It conforms to the position of the American Heart Association on research animal use adopted November 11, 1984.

A mongrel pig, 25 kg in mass, was anesthetized with 30 mg/kg of pentobarbitol. A total of 3000 units of heparin were administered intravenously to prevent blood clotting in the coronary arteries. The animal was
sacrificed using 40 meq of KCl via intravenous injection, and the heart was excised with approximately 5 cm of aorta and 5 cm of superior and inferior vena cava. The pulmonary artery, pulmonary vein and inferior vena cava were tied off and the pericardium was removed. The aorta, superior vena cava and left atrial appendage were cannulated and sutured onto three acrylic tubes, each 1 cm in diameter which, in turn, were connected to delrin “quick disconnect couplers” (Cole-Palmer, Niles, IL, USA) for rapid installation into the pumping chamber of the phantom.

The excised heart was perfused with fixative through its coronary arteries at a pressure of 100 cm of water for 1 h. The preservative was a modified Kaiserling fixative (Vacca 1985) consisting of 200.0 mL of formalin, 30.0 g of sodium acetate and 12.5 g of potassium nitrate dissolved in 1 L of distilled water. 10 mg of Na EDTA was also added as a calcium inhibitor. The heart was fixed in this solution for 3 days and then rinsed in normal saline solution.

Before installation, the heart in its saline bath was evacuated for 30 min to remove air bubbles. Figure 1 shows the heart in the Lexan pumping chamber suspended vertically above the atrial viewing port #4 from three inlets/outlets including: (1) the aortic root distal to the aortic valve and coronary os; (2) the right ventricle via a cannula inserted through the vena cava and crossing the tricuspid valve; and (3) the left atrium leaving the mitral valve intact. In this model, the right atrium is bypassed to prevent it from excessive contractions during hydraulic pumping. The pumping chamber is filled with isotonic saline, and a few drops of methiolate are added to further inhibit bacterial growth. When not in use, the phantom is refrigerated.

RESULTS

We scanned the porcine heart phantom using a Hewlett-Packard Sonos 1000 phased array scanner with a selection of transducers. Figure 2 shows long axis, 2.5 MHz, B-scans of the porcine heart obtained at end diastole (Fig. 2A) and end systole (Fig. 2B). Figure 2 also shows a 3.5 MHz short axis view of the heart at the level of the papillary muscles during diastole (Fig. 2C) and systole (Fig. 2D) as well as 3.5 MHz, apical views during diastole (Fig. 2E) and systole (Fig. 2F). In the right ventricle, the end of the acrylic cannula can be seen by the bright echo. In all these images, acoustic penetration, image quality, and visualization of cardiac anatomy is excellent.

The long-term image quality and cardiac wall motion in the phantom was tested by echocardiographic comparison to a human subject three months after construction of the phantom. Figure 3 compares a 3.5 MHz, short axis scan in a 22-year-old, 85 kg male (Fig. 3A) versus the analogous 5 MHz scan in the cardiac phantom (Fig. 3C). Acoustic penetration and image quality are better in the phantom with more echogenic myocardium. The figure also compares wall motion changes of left ventricular (LV) diameter (D) by M-mode plots from these short axis scans at the level of the papillary muscle. Figure 3B was used to measure a relative diameter change of ΔD/D = 59% in the human in excellent agreement with a 58% change in the LV diameter of the phantom (Fig. 3D).

Figure 4 shows long axis images of the left ventricle before (Fig. 4A) and after (Fig. 4B) a 2 mL injection of ultrasonic contrast agent (Albunex®, Molecular Biosystems, San Diego, CA, USA) into the left anterior descending coronary artery through a 22 gauge catheter as illustrated in Fig. 1. Note that in the cardiac phantom, the myocardium is normally quite echogenic, and thus it is difficult to visualize additional brightening due to the contrast agent. The perfusion of the agent into the myocardium from the coronaries is detectable in Fig. 4B through some subtle brightening (C), and through strong shadowing of the posterior wall due to attenuation in the contrast medium.

DISCUSSION

A beating cardiac phantom has been developed for diagnostic ultrasound using an excised porcine heart.
model. The fixed organ has been used to produce images of excellent quality with ventricular wall motion typical of human subjects for a period of four months. After almost daily use with nightly refrigeration, the heart retains excellent flexibility and acoustic properties. However, the surgical sutures have now begun to leak at the cannula and some visual appearance of epicardial tissue breakdown has begun so that the lifetime of four months for this prototype model has ended. Additional research in preservation techniques is necessary to extend this useful life.

This phantom design shows promise as a training tool in echocardiography by providing visual feedback of external cardiac anatomy for students as they learn...
Fig. 3. Short axis views and corresponding M-mode scans \textit{in vivo} (A and B), and in the phantom (C and D).

to manipulate transducers and catheters to obtain ultrasound images of internal cardiac structures. The phantom may also be useful for evaluations of ultrasound image quality. Finally, we have begun preliminary measurements of cardiac stroke volume in the phantom using the change in height of the blood-mimicking

Fig. 4. Long axis views of the phantom before (A) and after (B) injection of Albunex\textsuperscript{®} as a contrast agent. (C) marks myocardial brightening.
fluid in its reservoir. Thus, the phantom may become useful as a gold standard of comparison to ultrasound imaging stroke volume measurements from: (1) the Duke real-time volumetric scanner (von Ramm and Smith 1990); or (2) B-scan volume tracking techniques in commercial scanners.

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REFERENCES


