Inexpensive Ventricular Phantom for ECG-Gated Equilibrium Studies

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A simple ventricular phantom has been constructed to validate calculations of ejection fraction in radionuclide ECG-gated equilibrium studies. The R-wave simulator constructed from one integrated circuit can also be used as a stand alone device for testing computer interface and cable connections for the ECG R-wave synchronizer input.

J Nucl Med 21: 880–882, 1980

Although dynamic heart phantoms have been described for radionuclide cardiac studies (*1*), these have been relatively complex, effectively precluding their routine application in the majority of laboratories performing these studies. We have constructed a simple left ventricular phantom that is suitable for verification of ejection-fraction calculations from ECG gated equilibrium studies.

MATERIAL AND METHOD

The phantom is a single-chamber heart model constructed from a balloon, plastic tubing, and a large syringe (Fig. 1). The balloon and syringe are filled with pertechnetate (Tc-99m) solution to simulate blood pool activity. They are then placed in a torso phantom containing water and ~10 mCi of pertechnetate to provide simulated body background activity. The balloon is suspended by the plastic tubing in the left antero-lateral aspect of the body phantom to match the normal position of the left ventricle.

Motion of the ventricular chamber was produced by manually moving the syringe in and out, which expands and contracts the balloon. The ventricular phantom was operated at 3–10 beats/min depending on the size of the stroke volume. The balloon size is varied to simulate various ventricular sizes. By varying the stroke volume a wide range of simulated ejection fractions from 8–80% can be generated for study. The ejection fraction was controlled on a stroke-by-stroke basis by carefully moving the stroke volume in and out of the balloon at a constant rate, using a stop watch as time reference. Untoward balloon motion is prevented by suspending a surgical clamp to the lower end of the balloon (Fig. 1).

To indicate the beginning of each cycle an R-wave simulator is necessary. This was constructed using three inverters packaged in a single 7404 integrated circuit (IC) (Fig. 2). The first two inverters serve as a debounce switch (*2*) while the third inverter is connected to the cathode of a light-emitting diode (LED) to give visual indication of the simulated R wave's occurrence. The R-wave simulation was used simultaneously with the ventricular phantom. The switch of the R-wave simulator was pressed each time when the balloon was at its maximum volume during the simulated diastole.

All phantom studies were performed on a portable scintillation camera equipped with high-resolution, parallel collimator. Approximately 1 mCi of pertechnetate was diluted into a 10 ml solution, which was introduced in small increments into the balloon until the count densities between the balloon and the body background were approximately 2:1, similar to the left ventricular-to-background ratio in our clinical studies. This ratio was determined by acquiring a static image of the phantom on the computer and generating a profile across the body phantom at the level of the simulated ventricle. Images were obtained from the 45° LAO

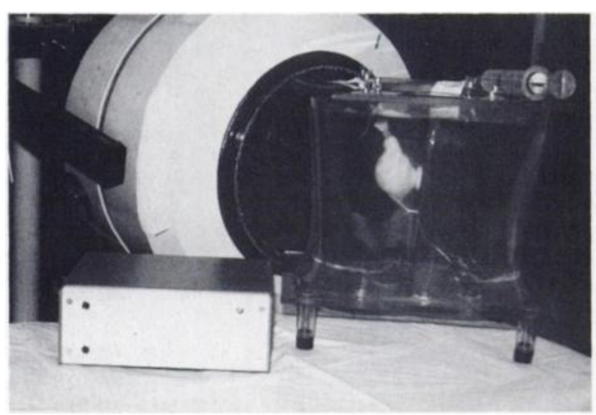

FIG. 1. Ventricular phantom set up to simulate left antero-lateral view of body phantom. Surgical clamp stabilizes bottom of balloon. Battery operated R-wave simulator at left provides square wave to computer each time switch (right upper corner) is pressed.

Received March 25, 1980; revision accepted May 9, 1980.

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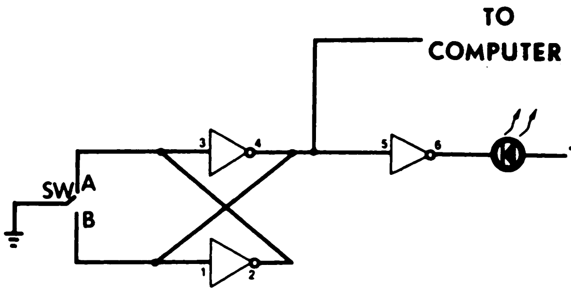

FIG. 2. Schematic of R-wave simulator. It consists of three inverters from 7404 integrated circuit. Two inverters at left debounce the single-pole, double-throw switch so that each time the switch is pressed, point A is grounded momentarily and square wave is sent to computer to indicate beginning of heart cycle. LED flashes each time switch is pressed to serve as visual indicator for successful square-wave generation.

projection; the count rate of the phantom usually ranged from 10K–14K cps.

The phantom data were collected in a dedicated minicomputer with 32K core memory and disk cartridge storage. Data collection was done in a 32 × 32 word mode with 28 frames representing the heart cycle. A setting of 200K counts were chosen for each frame with each study lasting 6–8 min. At the end of data acquisition, each 32 × 32 word mode frame was automatically interpolated to 64 × 64 word mode and stored on disk for subsequent analysis.

Ejection fraction (EF) analyses were independently performed by two observers without knowledge of the known EFs. Essentially, the counts over the ventricle (balloon) were obtained for each of the frames in order to generate a ventricular volume curve. The vendor-supplied computer program provided edge tracking of the ventricle based both on count threshold and the two dimensional second derivative (*3*). The edge of the ventricle in each frame is

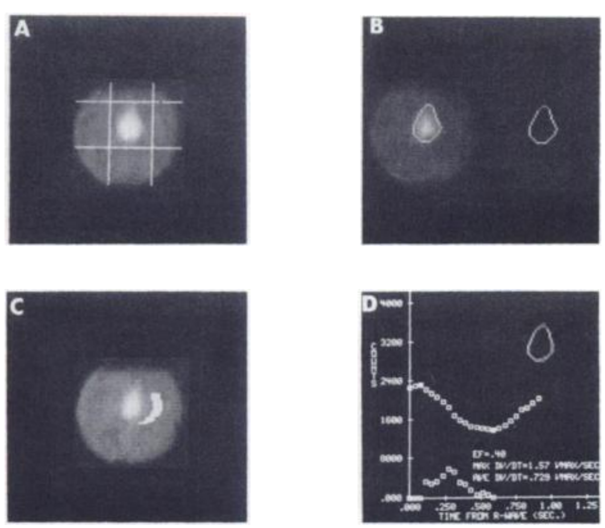

FIG. 3. Example of ejection-fraction calculation from phantom study. First, cursors are set up to enclose ventricle to be analyzed (A). Counts over ventricle in each frame are computed using area of interest defined by edge tracking of ventricle (B). Background is assigned as semilunar area lateral to ventricle (C), and when accepted by operator, background-corrected ventricular volume curve is generated (D). End-diastolic and end-systolic counts from curve permit calculation of EF.

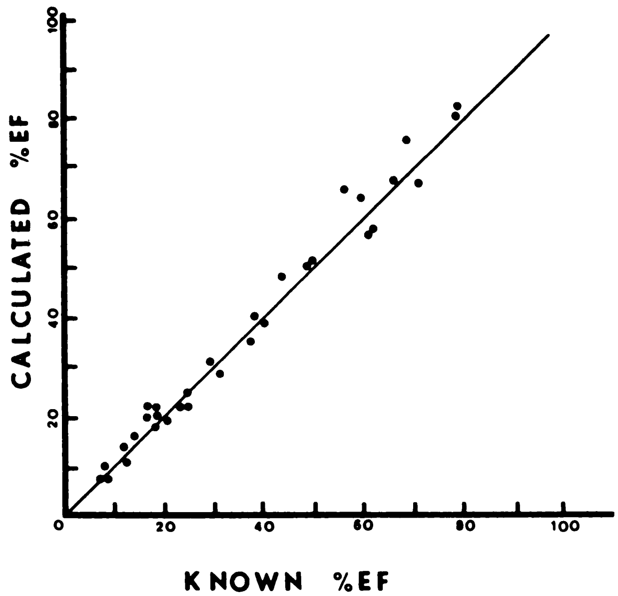

FIG. 4. Correlation of 32 calculated and known EFs in phantom study. Calculated % EFs (Y-axis) were closely related to known % EFs (X-axis) by equation Y = 0.98X + 1.59. Correlation coefficient (R) is 0.98. Standard error of estimate is 3.6.

first generated. The area enclosed by the edge represents a pulsating ventricular area of interest, providing ventricular counts for different frames. The threshold is adjusted until most or all of the points on the edge have been flagged using the second derivative criterion. After the program has generated the counts over the ventricle for each frame, an automatic background is assigned and, if it is accepted by the operator, the background-corrected ventricular volume curve will be produced.

Known EFs were determined from the balloon's actual end-diastolic and stroke volume and calculated EFs were obtained from the computer program (Fig. 3).

RESULTS

The results of 32 phantom studies are summarized in Fig. 4. The calculated EF correlated closely with the known EF (R = 0.98). The results from the two independent observers also correlated closely (R = 0.99). The interobserver differences ranged from 0–5% with a mean difference of 1.8 ± 1.5% (1 s.d.)

DISCUSSION

We have found the ventricular phantom very helpful for periodic verification of computer EF analysis consistency. This is especially important after major program updates from the computer vendor. The phantom data can also be used for training new technologists or physicians.

The R-wave simulator can itself be used alone to check the computer interface and cable connections for the R-wave synchronizer input. This is important if a problem occurs in the R-wave input and one is not sure whether the problem lies in the computer interface or in the ECG gating device itself.

As the phantom is a single-chamber heart model, it cannot completely match the complex geometry and motion of a human heart. However, it is a valuable quality control tool in identifying problem areas. If the operator or the computer program employed in EF analysis cannot provide satisfactory results with this simple heart model, one should be skeptical about the validity of the clinical results.

ACKNOWLEDGMENTS

The authors thank Mrs. Lois Bennett for assistance in preparation of the manuscript.

REFERENCES

1. NICKLES RF: A dynamic phantom for radionuclide cardiology. *J Nucl Med* 20: 547-549, 1979

2. WAKERY JF: *Logic Design Projects Using Standard Integrated Circuits.* New York, John Wiley & Sons, 1976, p 45

3. BELL PR: A one- and-two-dimensional least-squares smoothing and edge-sharpening method for image processing. Oak Ridge National Laboratory reprint ORNL/Tm-5222, Jan. 1976.