A New Phantom for Evaluation of Multigated Radionuclide Studies

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We evaluated a new cardiac phantom designed to simulate the action and function of the heart during multiple-gated acquisition studies. The phantom provides a simple method to evaluate any imaging system and the protocols used. The technical personnel involved in the performance of such studies may also be evaluated using this phantom.

Multiple-gated cardiac blood pool imaging is routinely used to assess and characterize ventricular performance in a variety of cardiac disorders. The information obtained may help to define the need for surgical or medical therapy or to ascertain whether specific therapy has been successful in improving cardiac function. In order to ensure the validity of multiple-gated cardiac studies, several factors have to be maintained, and these include: relatively stable cardiac function during data acquisition, minimal patient motion during imaging, relatively constant concentration of intravascular radiotracer during data collection, data acquisition of sufficient count density, and appropriate spatial resolution (*1*).

With the demand for nuclear cardiology procedures increasing (*2*), different types of computerized imaging equipment and software programs are being used to perform these studies. There has also been a parallel increase in the number of technical personnel performing such studies. While adequate protocols exist for quality assurance of conventional nuclear imaging devices [flood field testing and imaging bars and static emission organ phantoms (*3*)], quality assurance for nuclear cardiology is still being developed. There is a specific need for a simulated dynamic cardiac phantom to assess the performance of the equipment and programs used for gated studies. Quality assurance in nuclear cardiology, besides achieving uniformity of results, can also be used in personnel training and continuing education. A new, simple cardiac phantom (ADC Medical Inc., Farmingdale, NY) was evaluated to assess its performance.

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Materials and Methods

The "Jake" cardiac phantom is constructed of laminated acrylic material and contains a simulated heart chamber network, which is filled with varying amounts of radionuclide depending upon individual study requirements. Directly underlying the cardiac chamber is a circular background region with special filling/emptying valves to allow variation in the background activities (Fig. 1). An electronic drive module provides a mechanical stroke motion to a sliding lead shield, which provides an on/off source of photon flux to the input of the imaging camera, thus very closely simulating the filling and emptying motion of the human heart. The entire simulated cardiac cycle of the system is controlled by an internal microprocessor, which allows simulation of almost any cardiac motion or individual function. Heart rate can be varied from 40–120 beats/min on a digital display. Electrocardiographic signals of both positive and negative polarity from 1–10 m.v. (variable) are provided, and standard ECG leads are used to transmit trigger signals to the cardiac computer or ECG system employed. Several different shields (slides) are also available for simulation of different clinical situations, such as septal and apical akinesis.

The cardiac phantom was evaluated under different conditions. We altered the heart rate and background activity, and added simulated wall motion abnormalities. Experiments were carried out on four different occasions and data processed by four different persons. Data acquisition and processing was done with a standard nuclear medicine computer and software (Technicare Inc., Cleveland, OH). A general purpose, parallel hole collimator was used on a large-field-of-view scintillation camera. Usually, 1–3 mCi of [^{99m}Tc] pertechnetate was used as an emission source with a pulse height analyzer setting of 140 keV and window of 20%. A 16 interval multigated acquisition was performed with automatic gating interval selection and automatic termination of the acquisition when a prespecified count density of 200 counts/pixel over the ventricular chamber was reached. For analysis, an operator-controlled edge detection program was used. In this program, the operator selects a percent threshold for each quadrant in the region of interest, e.g., left ventricle. This method is particularly useful in studies presenting low data density or unusual ventricular shape.

During the first set of experiments, a variable background in the outside chamber in relation to the left ventricular cavity was used (Fig. 1). This was easily achieved by changing the concentration of technetium in the two cavities of known capacity (the ventricular chamber had a capacity of 125 ml while the outer background chamber accommodated 350 ml). A gradually increasing background activity was used and studies were performed at 20, 30, 40, and 60% background with a constant heart rate of 70 beats/min. Four different levels of the shield movement across the ventricular chamber were used to vary the systolic and diastolic ranges. In the second set of experiments, a constant background with a varying heart rate was used. The rates varied from 33–89 beats/min. In the third set of experiments, studies to calculate left ventricular ejection fraction (LVEF) were performed with shields simulating septal and apical akinesis in the setting of a fixed background with a constant heart rate.

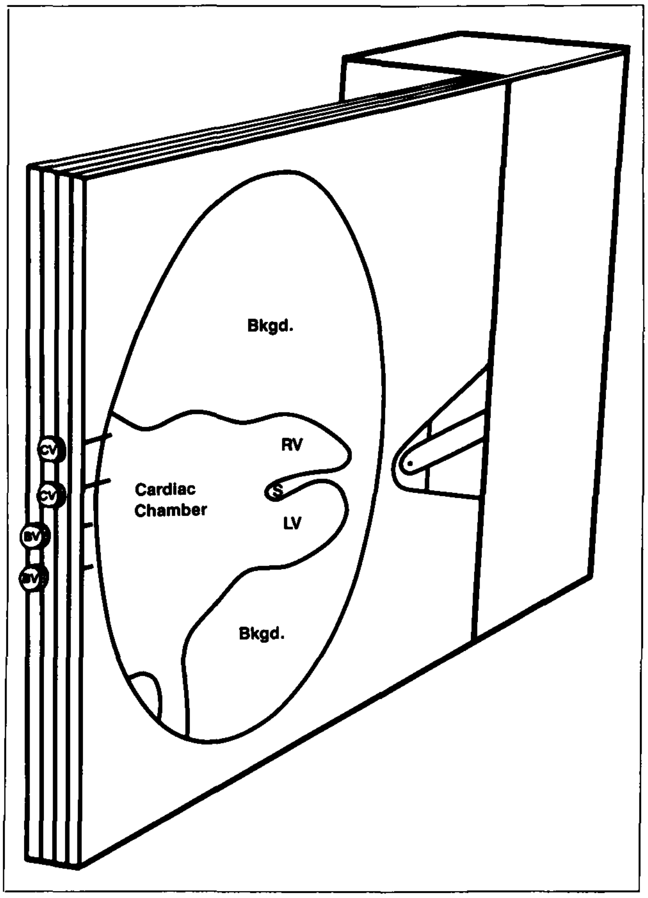

FIG. 1. Diagrammatic representation of bottom surface of cardiac phantom. Lead shield slides back and forth over LV to simulate systole and diastole. Bkgd. = background, RV = right ventricle, LV = left ventricle, S = septum, CV = cardiac filling valves, and BV = background filling valves.

TABLE 1. LVEF at Four Different Shield Levels with Varying Background Ratios

Background ratio	Level of sliding shield 1	2	3	4
20%	86	67	46	33
30%	82	66	47	31
40%	83	69	47	33
60%	84	67	48	31
Average with SD	84 ± 1.7	67 ± 1.2	47 ± 0.8	32 ± 1.1

Results and Conclusions

Changing background activity in relation to the ventricular chamber did not show any significant difference in the calcu-

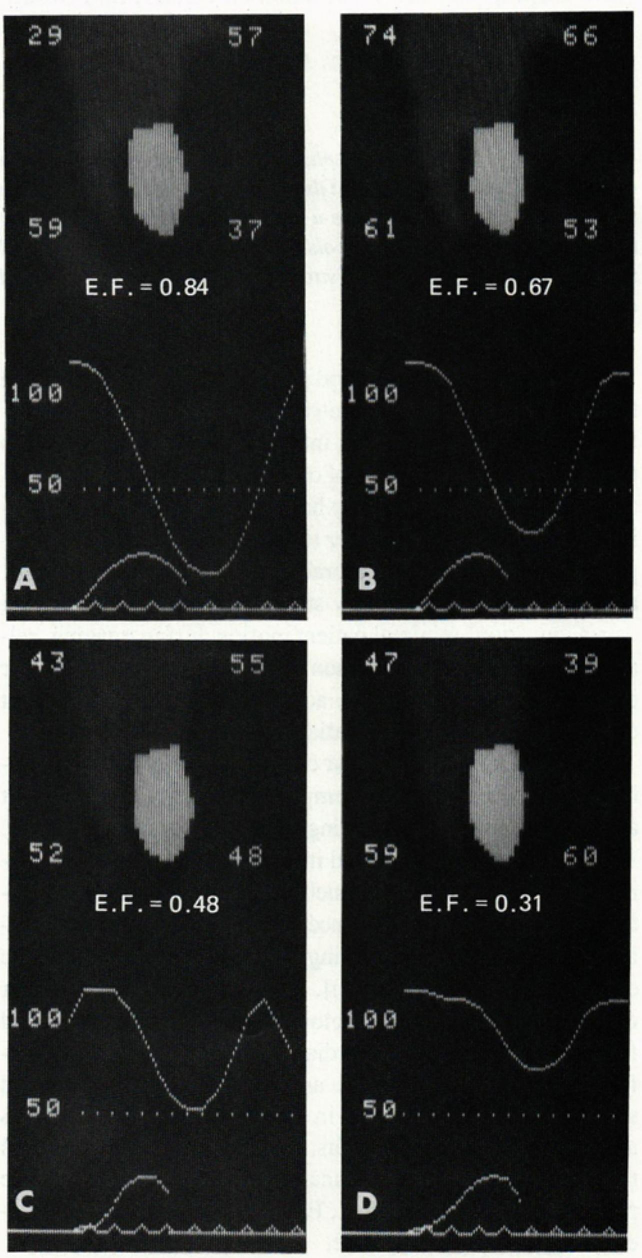

FIG. 2. Computer display of phantom with highlighted left ventricle region, ventricular volume curve, plot of slope, and ejection fraction—with sliding shields at levels from 1–4 (A–D).

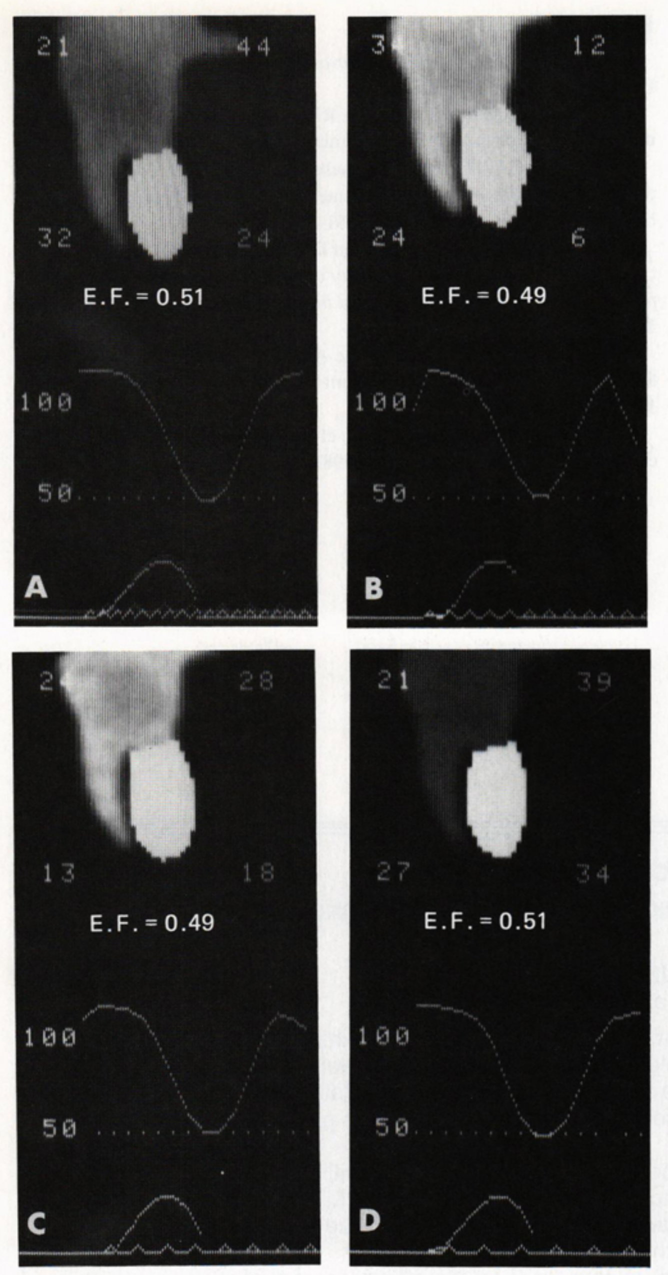

FIG. 3. Calculation of ejection fraction by changing phantom speed to simulate varying heart rates from 33 to 89 beats/min. (A) 33 beats/min; slope – vmax/s: average = 0.51 and maximum = 0.85. (B) 49 beats/min; slope – vmax/s: average = 0.55 and maximum = 1.19. (C) 71 beats/min; slope – vmax/s: average = 0.96 and maximum = 1.80. (D) 89 beats/min; slope – vmax/s: average = 1.39 and maximum = 2.34.

lated ejection fraction (Table 1). Processing the studies (including separation of the ventricular cavity from background and septal regions) was very simple. Figure 2 demonstrates the final edge gradient display of the ventricular volume curve scaled as a percentage of the end-diastolic volume, and the calculated ejection fraction at four known settings of the phantom designed to produce theoretical ejection fractions of 30, 45, 65, and 85%. A remarkable degree of reproducability of results was apparent when studies—performed on different occasions and processed by different operators to calculate LVEF—were compared (Table 1).

An increase in heart rate from 33 to 89 beats/min showed an associated increase in the average maximum ejection velocity, but because the phantom was designed with fixed volume of the cavity, no significant change in the ejection fraction was observed (Fig. 3). A considerable drop in ejection fraction occurred when shields with septal and apical hypokinesis were used (Fig. 4) to simulate a clinical situation.

Radionuclide gated equilibrium blood pool imaging is being increasingly used to study cardiac function. This approach provides a means for imaging the cardiac blood pool at various times during cardiac cycle. The rapid development of nuclear imaging devices during the last decade has resulted in the availability of high quality diagnostic information to aid in management of numerous clinical problems. The importance of regular quality control of imaging instrumentation and software to maintain a high level of diagnostic accuracy is well known. In testing the field uniformity of conventional imaging equipment, resolution and spatial distortion by standard phantoms are used (*4*). There is a distinct need for simple and readily acceptable quality assurance procedures for both

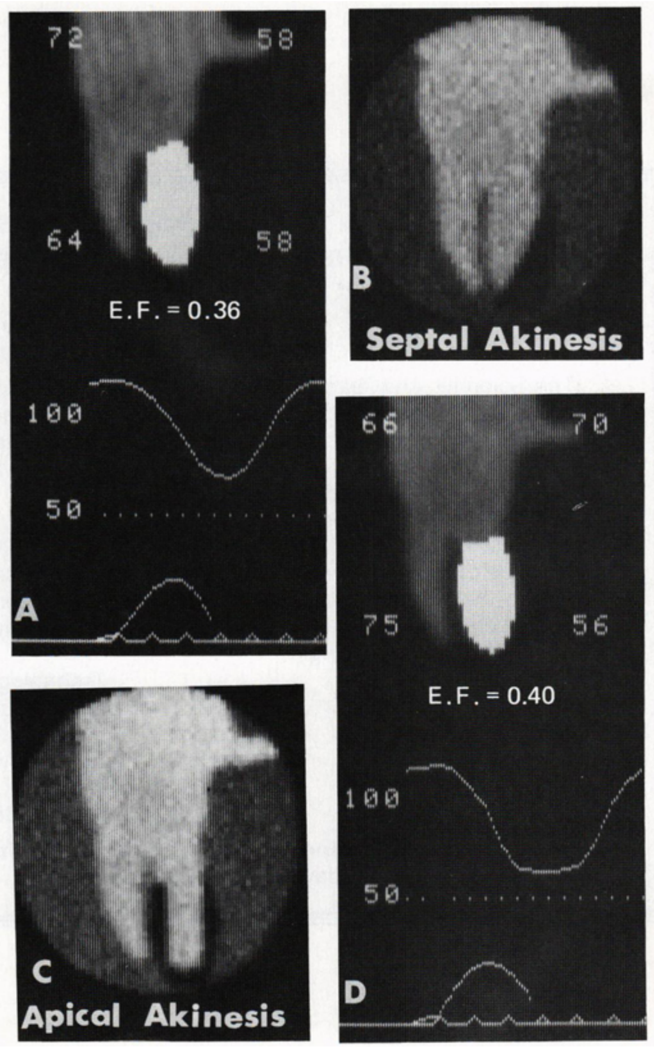

FIG. 4. Use of different shields provides simulation of septal (A,B) and apical (C,D) akinesis, and thus allows for processing of multigated cardiac studies in pathological situations. (A) 79 beats/min; slope – vmax/s: average = 0.84 and maximum = 1.37. (D) 81 beats/min; slope – vmax/s: average = 0.94 and maximum = 1.70.

the hardware and software used in recording the dynamic events of the cardiac cycle. Some other phantoms, such as the Vanderbilt cardiac phantom (Amersham Corp., Arlington Heights, IL) and a precision pump to simulate the dynamic events of the beating heart, have also been available for the quality control of multigated cardiac studies (*5,6*). The "Jake" cardiac phantom appears useful for routine quality assurance of multigated cardiac studies and could provide standards for consistency, research, and development. This phantom was found to be simple to use and received high staff acceptability.

Acknowledgment

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