

Development and Evaluation of a Dynamic Cardiac Phantom for use in Nuclear Medicine

Marcos A. Dullius, Ramon C. Fernandes, and Divanízia N. Souza

Abstract—The aim of this study was to develop a dynamic cardiac phantom for quality control in myocardial scintigraphy. The dynamic heart phantom constructed only contained the left ventricle, made of elastic material (latex), comprising two cavities: one internal and one external. The data showed a non-significant variation in the values of left ventricular ejection fraction (LVEF) obtained by varying the heart rate. It was also possible to evaluate the ejection fraction (LVEF) through different arrays of image acquisition and to perform an intercomparison of LVEF by two different scintillation cameras. The results of the quality control tests were satisfactory, showing that they can be used as parameters in future assessments. The new dynamic heart phantom was demonstrated to be effective for use in LVEF measurements. Therefore, the new heart simulator is useful for the quality control of scintigraphic cameras.

Keyword—heart, nuclear medicine, phantom

INTRODUCTION

MYOCARDIAL scintigraphy allows the evaluation of patients diagnosed with or suspected to have coronary artery disease (CAD) through the administration of radiopharmaceuticals. Scintigraphic images enable information to be obtained on the functioning of the heart for ischemia detection, the determination of myocardial viability and the evaluation of pre- and post-operative cardiac risk, for example.

The reviews of myocardial perfusion obtained by tomographic techniques associated with an electrocardiogram (ECG) provide diagnostic information about the perfusion of the left ventricle, which then allows an evaluation and risk estimation of patients with CAD [1-3].

Cardiology in nuclear medicine in Brazilian health institutions has evolved in parallel with the most advanced international centers in the industrial production of new tracers and technological advances in equipment for the acquisition and processing of images to diagnose various heart diseases, and it also helps to identify the reversibility of left ventricular dysfunction and it helps in surgical selection [4].

Improvement in the standards of efficiency, reliability and technology used in diagnostic practices in nuclear medicine, as in other specialties, requires adequate quality control. Quality assurance covers all efforts so that the resulting image of a particular procedure approximates the ideal, free of errors and

artifacts [5, 6]. The main reason for performing quality control tests on equipment that uses ionizing radiation is to ensure that the patient receives the best possible diagnosis with minimal radiation exposure [7].

One way of ensuring the quality of procurement procedures for scintigraphic images by the cameras used in nuclear medicine is through the use of phantoms in the tests required to evaluate quality. The Brazilian standard CNEN NE-3.05, National Commission of Nuclear Energy (CNEN), recommends using appropriate simulators for tests of field uniformity, linearity, and spatial resolution of scintigraphic cameras [8].

Images of the dynamic heart phantom have allowed evaluations of the ability of a system to trace cardiac motion. Several dynamic heart phantoms have been designed to reproduce the sequence of pulses or cardiac-specific movements, such as compression of the left ventricle [9-11].

The dynamic cardiac phantom simulates cardiac motion and blood flow in the heart through periodic movements. A mechanism is needed to enable the electrocardiogram (ECG) simulator coupled to phantom to control the time of end diastole and end systole. This coupling allows the ejection fraction of the left ventricle to be measured. Fixing a value of LVEF in the phantom is possible in order to verify the accuracy of the system to acquire images from the scintillation camera. In order to perform tests with dynamic simulators it is necessary to be able to represent the vital signs of a patient so that the images of such objects are those which can be obtained from patients [12].

The phantoms allow the training of nuclear medicine professionals and analysis of the functionality of organs and systems of image acquisition without the need to obtain images from patients [13].

Given the importance of the appropriate quality of equipment for image acquisition and for reconstruction programs for the images used in nuclear medicine, the aim of this study was to develop a dynamic cardiac phantom.

The objective of a dynamic heart phantom is to obtain practical measures of LVEF. Images obtained with these objects, using the radiopharmaceuticals used in nuclear medicine and cardiology, were also used in quality control for the intercomparison of measurements of ejection fraction taken by two different computed tomography cameras using single photon emission.

MATERIALS AND METHODS

The images were acquired by two scintillation cameras, APEX SPX4 and APEX SPX6, both of the Elscint/Israel brand, with a parallel-hole collimator for low power and high resolution (*LEHR*). A Funbec/Brazil model 4-1CN cardiac

M. A. Dullius, with the Federal University of Sergipe, Physics Department, São Cristóvão-SE, Brazil (phone: +55 79 2105 6725; fax: +55 79 2105 6708; email: madullius@gmail.com).

R. C. Fernandes with the Federal University of Sergipe, Electrical Engineering Department, São Cristóvão-SE, Brazil (phone: +55 79 2105 6834; fax: +55 79 2105 6837; email: amsten@hotmail.com).

D. N. Souza, with the Federal University of Sergipe, Physics Department, São Cristóvão-SE, Brazil (phone: +55 79 2105 6725; fax: +55 79 2105 6708; email: divanizia@gmail.com).

monitor was coupled to the scintillation cameras to provide traces of the ECG and heart rate and to beat the alarm system.

The dynamic heart phantom constructed only contains the left ventricle, made from elastic material (latex liquid), which consists of two cavities: one internal and one external. The average volume of the internal cavity is 180 ± 4 mL and the mean volume of the external cavity is 160 ± 5 mL.

In order to obtain the images in the SPECT (single photon emission computed tomography) system, the inner cavity is filled with water and the external cavity is filled with technetium-99m associated with the drug sestamibi, dissolved in water. The external cavity simulates the shape of the left ventricle. Fig. 1 (a) shows a schematic of the cavities of the dynamic heart phantom. Fig. 1 (b) shows a photograph of the dynamic heart phantom.

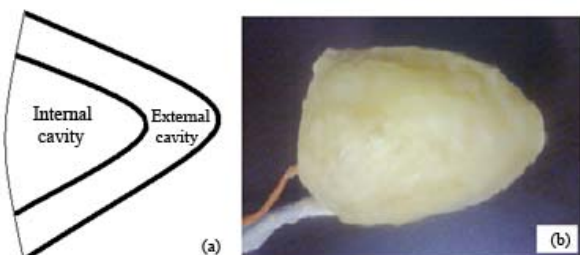


Fig. 1 (a) Schematic of the construction of the dynamic heart phantom and (b) the dynamic heart phantom

The dynamic part of the phantom is driven by a motor connected to a disk. The disk connects to a piston that drives the syringe, and the plunger injects and removes certain volumes of water from the ventricle, creating the characteristic movement of the ventricles. The volume change is necessary to simulate the variation between systole and diastole, essential for calculating the ejection fraction. Figure 2 (a) shows the main impulse of the piston connected with the syringes.

The frequency of the pump compression and decompression of the piston can vary from 50 to 90 bpm (beats per minute). The change in ventricular volume between diastole and systole can be changed to 30, 40, 48, 50, 60, 70, 80, 90, 100, 110, 112, and 120 mL.

The motion of the heart is coupled to a simulated electrocardiogram (ECG). The pulse of the R wave is coupled to the beating of the heart simulator. The simulator mimics the ECG waveform of a heartbeat. The ECG simulator can control the speed of the compression and decompression pump, or change the speed of the simulated heartbeat. The ECG simulator can also change the height of the output pulse of 1 mV to 2 mV and control the waveform of the heartbeat, or simulate abnormal variations in heart rate, as can occur in heart disease. Figure 2 (b) shows the circuit board developed for the ECG simulator. It should be noted that the development of the dynamic heart phantom was based on a document of the International Commissions on Radiation Units and Measurements (ICRU), which deals with phantoms and

computational models for therapy, diagnosis and radiation safety [14].

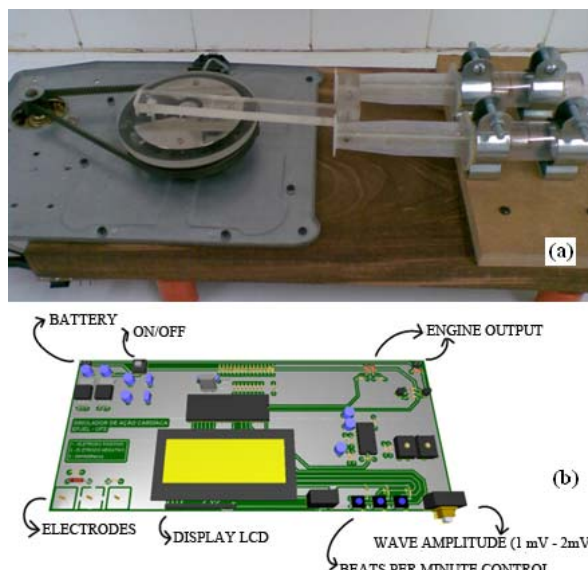


Fig. 2 (a) Image of the main impulse of the piston connected with the syringes. (b) Circuit board of the ECG simulator

RESULTS AND DISCUSSION

Images were obtained of the dynamic heart phantom through tomographic acquisitions by scintillation camera SPX6 APEX, at 180° to the heart, from the 45° right anterior oblique (RAO 45°). Image acquisition was synchronized with the ECG. Eight images were acquired of a simulated heartbeat.

First, the dynamic heart phantom was calibrated to provide a left ventricle in end diastole (EDV) volume equal to 160 mL of end systole (ESV) equal to 80 mL, i.e. LVEF = 50%. The images were acquired with a 64×64 pixel matrix. Figure 3 shows the image obtained by the dynamic heart phantom. The value for left ventricular volume in end diastole (EDV) was 162 mL and the value in end systole (ESV) was 79 mL, thus providing an LVEF value of 51%.

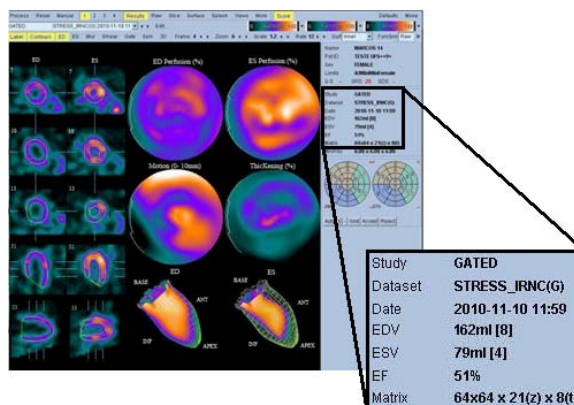


Fig. 3 Image obtained by the dynamic heart phantom, showing the values of cardiac volume obtained

In order to evaluate the influence of heart rate on left ventricular ejection fraction measurement, the rate of simulated heartbeats per minute (bpm) was raised from 50 to 90 in intervals of 10. Ten measurements were taken for each heartbeat. The images were acquired with a 64×64 array of pixels. The data showed a variance of 3.1%, i.e. a non-significant variation in the values of ejection fraction obtained by varying the heart rate. Figure 4 shows the results obtained with their respective standard deviations.

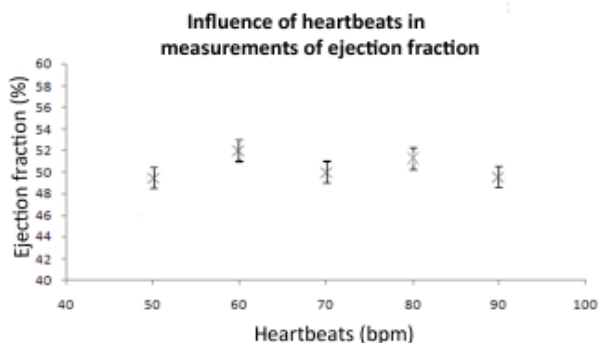


Fig. 4 Graph showing the influence of heart rate on the measurement of left ventricle ejection fraction

We tested the influence of the image acquisition matrix on the ejection fraction of the left ventricle. For this, we acquired images of the dynamic heart phantom with pixel arrays of 64×64 , 128×128 and 256×256 . This evaluation found that beats were acceptable with a 20% variation in the R-R interval of the ECG. Ten measurements of the same parameters were taken for each array. Figure 5 is a graph showing the change in ejection fraction of the left ventricle according to the pixel acquisition array.

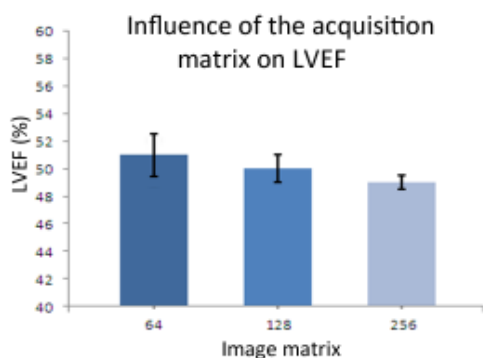


Fig. 5 Graph showing the influence of the acquisition matrix on LVEF

Using the dynamic cardiac phantom, a comparison was made between the left ventricle ejection fractions obtained from the two different scintigraphic devices. For these measurements, the phantom was calibrated in order to provide the same values of left ventricular ejection fraction.

We established three values of ejection fraction for the dynamic cardiac phantom: 30% (low value), 50% (average) and 70% (high value). The values obtained by the APEX SPX4 and APEX SPX6 cameras were satisfactory for all values of ejection fraction tested. Table 1 shows the values of ejection fractions for both cameras. It is noteworthy that the two acquisition systems use the same image processing program. Finally, we found that it is possible to study the variation in measurements taken by different equipment using this phantom.

TABLE I
MEASUREMENTS OF EJECTION FRACTION (%)

Camera	Values for ejection fraction ^a		
	30(%)	50(%)	70(%)
APEX SPX4	29 ±2	51 ±3	72 ±3
APEX SPX6	30 ±2	52 ±3	72 ±3

In this study, no significant differences were found between the values of ejection fraction obtained by both cameras.

CONCLUSIONS

In this study we developed and evaluated the performance of a dynamic heart phantom for the quality control of scintillation cameras.

The dynamic heart phantom allowed us to evaluate the left ventricle ejection fractions of 30%, 50% and 70% through tomographic images of the heart at 180° from the right anterior oblique (RAO - 45°). The movement of the dynamic simulator was generated by a motor connected to a piston, and the beating of the heart phantom was synchronized through a simulated electrocardiogram. Moreover, the dynamic heart phantom allowed the influence of heartbeat on the measurement of LVEF to be evaluated. It was also possible to assess LVEF using different image acquisition arrays. Additionally, the ejection fraction values determined by two different scintillation cameras were compared. The results of the quality control tests were satisfactory, showing that they could be used as parameters in future assessments.

The new dynamic heart phantom was shown to be effective for measurements of the left ventricle ejection fraction. Therefore, the new heart simulator is presented for effective use in the quality control of scintigraphic cameras.

ACKNOWLEDGMENTS

The authors thank the National Council for Scientific and Technological Development (CNPq) for financial support and the Clinic of Nuclear Medicine Endocrinology and Diabetes Ltd. (CLIMED) for their assistance with data validation.

REFERENCES

[1] S. Khan, J. Wilde, "Design of a dynamic cardiac MR phantom for the evaluation of cardiac MR systems." International Congress Series. Vol. 1256, pp.1165-1170, 2003.

- [2] B. A. Zanchet, "Desenvolvimento de uma ferramenta para análise quantitativa de espessamento miocárdico através do processamento imagens médicas digitais." 2007. Monograph (Bachelor of Computer Science). Federal University of Pelotas, Pelotas/RS.
- [3] A. L. Baert, K. Sartor, "Diagnostic Nuclear Medicine." Ed. 2a., Springer, 2006.
- [4] A. C. Camargo, "Otimização dos procedimentos de preparação marcação e controle de qualidade do glucarato-^{99m}Tc para diagnóstico do infarto agudo do miocárdio." 2007. Dissertation (Masters in Nuclear Technology - Applications). São Paulo/SP.
- [5] IAEA-International Atomic Energy Agency. "Quality control of nuclear medicine instruments. Vienna", 1991. (IAEA-TECDOC-602).
- [6] IAEA-International Atomic Energy Agency. "Quality assurance for SPECT systems". Vienna, 2009.
- [7] K. Matusiak, M. W. Radwanska, A. Stepien, "Dynamic heart phantom for the quality control of SPECT equipment". *Physica Medica*. Vol. 24, pp. 112-116, 2008.
- [8] CNEN-NE 3.05, Comissão Nacional de Energia Nuclear, "Requisitos de Radioproteção e Segurança para Serviços de Medicina Nuclear", Rio de Janeiro, 1996.
- [9] D. Debrum, *et al.*, "Volume measurements in nuclear medicine gated SPECT and 4D echocardiography: validation using a dynamic cardiac phantom." *International Journal of Cardiac Imaging*, Vol. 21, pp. 239-247, 2005.
- [10] S. Kee, *et al.*, "Development of a Dynamic Heart Phantom Prototype for Magnetic Resonance Imaging". Bioengineering Conference, IEEE 36th Annual Northeast. DOI: 10.1109/NEBC.2010.5458235, 2010.
- [11] G. Germano, *et al.*, "Automatic Quantification of Ejection Fraction from Gated Myocardial Perfusion SPECT." *The Journal of Nuclear Medicine*. Vol. 36, pp. 2138-2147, 1995.
- [12] H. Bergmann "Test phantoms in nuclear medicine: planar gamma camera." *Radiation Protection Dosimetry*. Vol. 49, pp. 285-293, 1993.
- [13] K. J. Murray, A. T. Elliott, J. Wadsworth, "A New Phantom for the Assessment of Nuclear Medicine Imaging Equipment." *Physics in Medicine & Biology*. Vol. 24, pp. 188-192, 1979.
- [14] ICRU-International Commission on Radiation Units and Measurements. "Phantoms and computational models in therapy, diagnosis and protection." ICRU REPORT 48, 1992.

M. A. Dullius Graduated with a Bachelor in Physics with Emphasis on Medical Physics, Federal University of Rio Grande (2008), an undergraduate degree in Physics from the University of Rio Grande (2008) and an MSc in Physics from the Federal University of Sergipe (2011), specializing in the following subjects: nuclear medicine, quality control, professional training and the development of nuclear medicine phantoms.