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# Cardiac Phantom for Gated Single Photon Emission Computed Tomography (GSPECT)

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***Abstract*—Gated single-photon emission computed tomography (GSPECT) is the most important technique for the heart imaging, but the patients instability and the physiological cardiac function variability make studies difficult to evaluation and comparing different imaging techniques. So, a dynamic cardiac phantom (DCP) was constructed at our nuclear medicine unit-National cancer institute, which can be used as a reference to compare the reconstructed volumes & ejection fractions for GSPECT. GSPECT data were acquired using the DCP with a standard dual-head gamma camera, and the reconstructions were carried out using the Mirage software released by Segami. The validity of DCP for GSPECT imaging was evaluated by imaging of 12 different volumes of the phantom. Linear regression analysis was performed to assess the correlation between the real versus the measured volumes & ejection fractions for all the 12 different volumes. Then we assessed the correlation between real EF and the GSPECT-quantified EF for some acquisition parameters as frame/cycle (8 versus 16), and time/projection (40 versus 20 sec). Results obtained in our study showed that the constructed DCP is suitable to GSPECT imaging. Also, the study shown that in the case of acquisition parameters it's enough to using the 8 frames per cardiac cycle with 40 sec time per projection.**

***Index Terms*—Gated, SPECT, cardiac, phantom**

## I. INTRODUCTION

The human heart is a 3-D organ with a complex shape and a periodic motion. For a correct evaluation of systolic function, a 4-D reconstruction (3-D volumes as a function of time) seems to be necessary. However, no reference method currently exists for cardiac volume reconstruction; doubtless because of the intrinsic complexity and the recent nature of all multidimensional imaging techniques of the heart. Most of the studies carried out compared two or more modalities: for example, echocardiography vs. gated single-photon emission computed tomography, SPECT (Nichols et al. 2000), 3-D echocardiography vs. nuclear magnetic resonance, NMR (Chuang et al. 2000; Bauer et al. 2001) or vs. Isotopic entriculography (Nosir et al. 1998) or nuclear medicine vs. angiography (Yamazaki et al. 1997).

Results sometimes pointed out differences of volume quantification, but it is often difficult to select one method in preference to another, without an accepted standard. Calibration of methods using a beating cardiac phantom, with known parameters, is an appropriate response to these difficulties, and a necessity before clinical evaluation.

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Many studies have been done on cardiac volume measurement to determine the accuracy and reliability with different modalities (Lowe et al. 1993; Reicheck 1987; Hoilund-Carlsen et al. 1984). They were tested mainly on animal or human models (Byrd et al. 1989) (ventricular mass and volume determined postmortem) and sometimes on static phantoms of different materials (Aakhus et al. 1994). Physiological cardiac rhythm and systolic function variability make studies difficult in living subjects. Similarly, static phantoms are very restrictive. Studies on isolated beating hearts have been carried out with US imaging (Smith et al. 1995) but cannot be realized with gated SPECT because the exam depends on radioisotope uptake by a living cell.

## II. MATERIALS AND METHODS

### A.MATERIALS:

Dynamic cardiac phantom (DCP) (Fig. 1) was constructed in our nuclear medicine unit to studying the heart quantification by Gated single photon emission computed tomography (GSPECT). It was made from a mechanical pump system, which was connected to an ellipsoidal model of left ventricle made from rubber balloon and surrounded by a thorax phantom. At this time, no right ventricle is available to allow two-chamber examinations. Ventricular filling and emptying were achieved by mans of a noncircular motor motion on a reservoir, which withdrew/ added water from/ into the balloon, yielding a sinusoidal filling and emptying pattern. To simulate the ventricular wall, the balloon coated with a mixture of glue and 99mTc, it composes using 5 ml glue add with 99mTc (0.025 mCi/ ml3) and shake the solution to be homogenous, then we coated the cardiac balloon with it. 20 min later we coated the balloon with another layer of free glue (without 99mTc) to prevent the chest phantom contamination, it leaved about 30 min to dry, then we installed the DCP in the thorax phantom replacing the static cardiac phantom of Data-Spectrum, Chapel Hill, NC.

The pump rate was controlled such that we obtained constant heart rate of about 65 beats. $min^{-1}$. An electrical contact generated a voltage peak when the pump reached its outermost position (end-diastolic (ED) volume of the ventricular cavity) to simulate the patient's electrocardiogram (ECG) trigger. A fixed 33.8 ml3 stroke volume is applied for each ejection fraction, but systolic volume is adjustable, starting from a volume of 22.5 ml3. The diastolic volume was varied from 56.3 to 96.9 ml3, and the systolic volume from 22.5 to 63.4 ml3, using steps of 3.75 ml3, the corresponding ejection fraction varying from 60% (a value close to the mean normal value) to 34% (pathologic cases). Twelve precisely

known volumes were obtained, which is sufficient to draw conclusions within the range of available values. The volume of the DCP is corrected for measuring of the lower part only (the coated part), which is the 75% of the total volume Fig 2. The volumes &ejection fractions thus obtained were used as the gold standard.

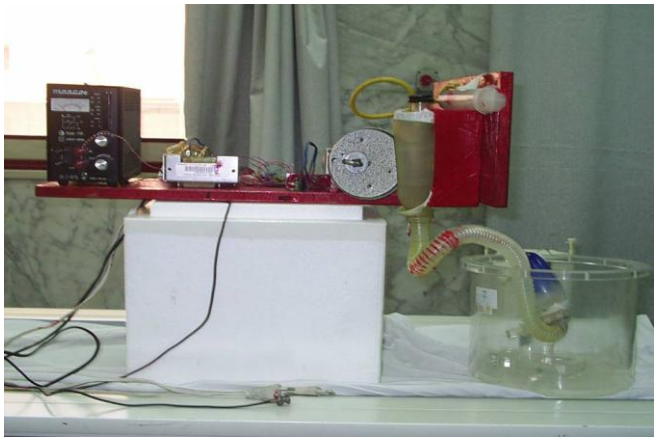

Fig. 1; dynamic cardiac phantom (DCP)

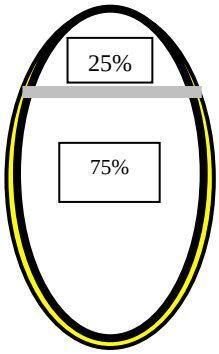


Fig. 2. Correction of Ventricular Volumes & Ejection Fraction when the Dynamic Cardiac Phantom was used.

B- METHODS:

Image Acquisition: The scintillation camera used in this study was the E.CAM (Dual-Head Variable-Angle System) from Siemens, with the low energy general purpose collimator. Image Acquisition started using the DCP, which described above by imaging 12 different volumes. The starting ESV was 22.5 ml and end at 63.4 ml, and the starting for EDV was 56.3 ml and ending EDV was 96.9 ml. There was arranging of 3.75 ml in volume between each set of acquisition images. Then we acquired projection data to study the effects of different bin frame/cycle (8, 16) and time per frame (40, 20 sec) on the measured EFs, each volume calculation was repeated three times.

All images were acquired using 15% energy windows. We used 40 sec/projection & 32 projection views with 90o angle orbital motion. The acquisition matrix was 64 x 64 with zoom factor of 2.3.

Image reconstruction; The image reconstruction method used was the filtered back projection, Attenuation coefficient is 0.11, Filter type is Butterworth with Cut of frequency (cyc/cm): 0.8, with order 5, the reconstructed images are saved which used for analysis.

The DCP surfaces LV volumes are determined in terms of the total number of voxels (volume elements) inside the surface. From this calculation the largest cavity volume throughout the cardiac cycle is defined as the end-diastolic volume (EDV), the smallest cavity volume as the end-systolic volume (ESV) and left ventricular ejection fraction (EF) is calculated as the stroke volume (EDV-ESV) divided by EDV.

$$EF\ (\%) = (EDV - ESV / EDV) * 100$$

Statistical Analysis: The results of the DCP gated processing were expressed by liner regression and Bland-Altman analysis for volume determination & EFs versus the real volume & real EFs.

When the values can statistically expressed with 12 point [Yi-Hwa Liu-2002], [NGUYEN L. D-2003], the results of the 12 DCP gated processing were expressed by liner regression and Bland-Altman analysis for volumes determination & EFs versus real volumes & real EFs. The percent difference was calculated. Then comparing real with measured ESs, EDs & EFs, and effect of different bin frame/cycle (8, 16) and time per frame (40, 20 sec) on the measured EFs, each volumes calculation was repeated three times.

## III. RESULTS & DISCUSSION

The GSPECT preprocessing application enables assessment of beat normalization for DCP to ensure quality of projection data before processing Figure (3). This application automatically creates; sinogram image, beat histogram (to evaluate heart rate variation over total study time) and curves of accepted beats per projection, and average heart rate per projection, also it displays the data of stop condition, total counts in study, number of time bins, number of accepted beats, number of rejected beats, framing mode (percent of forward framing) and zoom factor used during acquisition.

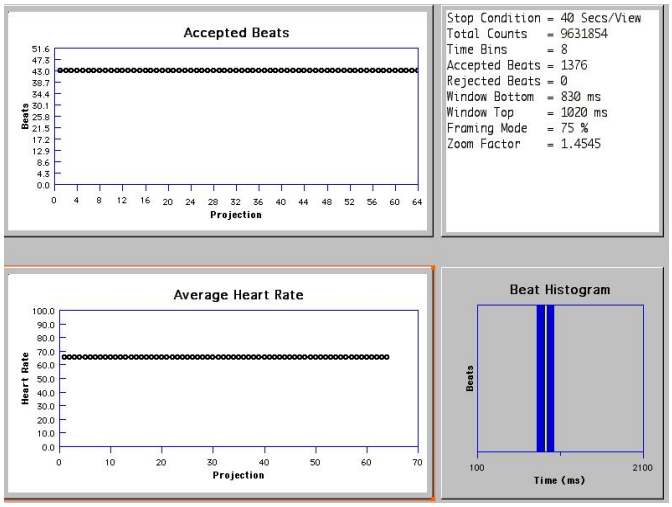


Figure (3) assessment of beat normalization for DCP

***1-Real versus measured volumes & ejection fractions;***

Table 1 shows the real and measured (R, M) for both end systolic end dyastolic (ES, ED) volumes and ejection fractions (EF) with the percent difference between them. Figures 4 and 5 shown, respectively volumes and ejection fraction measured by GSPECT, relative to the real phantom values. The results are similar, especially for ejection fraction, where the maximum difference between both real and measured is less than 11%. Regression line was plotted, and correlation coefficients are good: r = 0.975. The comparison between the y & x line indicates a 35% overestimation of measured volume by the GSPECT examination, which leads to high values of ejection fractions. Similarly, the correlation coefficient for ejection fraction is good; both give a correct evaluation of global systolic function on the phantom.

Also, from the Bland-Altman plots, (Figure 7) to check the accuracy, it can be seen that the offset is equal to zero. And the mean and standard deviation of the difference is 4.03 ± 1.79; the regression equation shown is y=0.0861x - 0.0697; r=0.364.

| | RES | MES | % deff | RED | MED | % deff | REF | MEF | % deff |
|---|---|---|---|---|---|---|---|---|---|
| 1 | **22.5** | 24 | -6.3 | **56.3** | 66.2 | -15 | **60** | 63.7 | -5.9 |
| 2 | **28** | 29.2 | -4.1 | **60** | 73.1 | -17.9 | **53.3** | 60.1 | -11 |
| 3 | **31.7** | 34.8 | -8.9 | **63.8** | 74.4 | -14.3 | **50.3** | 53.2 | -5.5 |
| 4 | **33.8** | 38.1 | -11 | **67.5** | 81.3 | -17 | **50** | 53.1 | -5.9 |
| 5 | **37.5** | 40.8 | -8.1 | **68.9** | 82 | -16 | **45.6** | 50.2 | -9.3 |
| 6 | **41.3** | 45.2 | -8.7 | **75** | 94.9 | -21 | **45** | 52.4 | -14 |
| 7 | **41.7** | 48 | -13 | **78.8** | 100.4 | -21.6 | **47** | 52.2 | -9.9 |
| 8 | **48** | 56.8 | -15 | **84.3** | 101.8 | -17.2 | **43.1** | 44.2 | -2.6 |
| 9 | **50.6** | 58 | -13 | **86.3** | 104.5 | -17.5 | **41.3** | 44.5 | -7.1 |
| 10 | **51.8** | 60.8 | -15 | **90** | 113.4 | -20.6 | **42.4** | 46.4 | -8.5 |
| 11 | **61.1** | 73.2 | -17 | **93.8** | 116 | -19.2 | **34.8** | 36.9 | -5.6 |
| 12 | **63.4** | 75.1 | -16 | **96.9** | 122.9 | -21.2 | **34.6** | 38.9 | -11 |

Table (1)

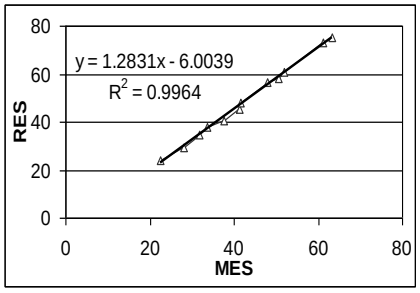


Figure (4)

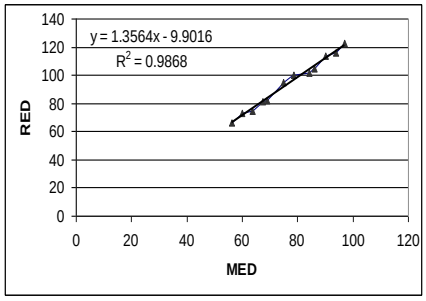


Figure (5)

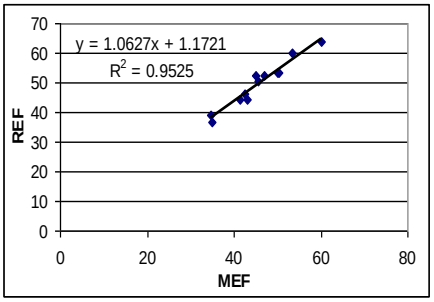


Figure (6)

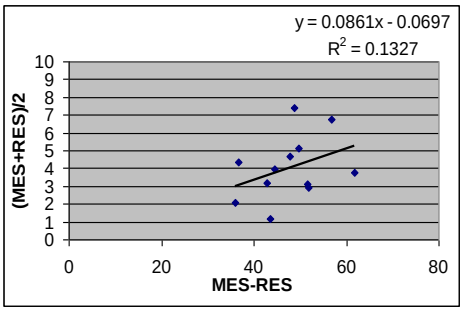


Figure (7)

Bland-Altman plot comparing differences in EFs computed from GSPECT versus the real EFs. in which the mean = 4.03, SD= 1.79, mean +2SD = 7.6 & the mean -2SD = 0.46.

***2-Effect of time bin frame/cycle (8, 16) on EF;***

Linear regression analysis was performed to assess the correlation between the real EF and the GSPECT-quantified EF for 8 and 16 frame/cycle. It no significant difference due to the changing from 8 frame to16 frame although the 16 frame showed a slight trend towards higher correlation for EFs (r= .996) than 8 frame (r = 0.975), as seen in Figure 8.

So it's enough to using the 8 frames per cardiac cycle with an accepted LVEF.

| | REF | MEF (8 f./cyc.) | % deff | MEF (16 f./cyc.) | % deff |
|---|---|---|---|---|---|
| 1 | **60** | 63.7 | -5.88 | 64.4 | -6.83 |
| 2 | **53.3** | 60.1 | -11.2 | 57.9 | -7.89 |
| 3 | **50.3** | 53.2 | -5.54 | 53.1 | -5.32 |
| 4 | **50** | 53.1 | -5.9 | 54.5 | -8.26 |
| 5 | **45.6** | 50.2 | -9.3 | 48 | -5.06 |
| 6 | **45** | 52.4 | -14.1 | 48.2 | -6.64 |
| 7 | **47** | 52.2 | -9.86 | 51 | -7.75 |
| 8 | **43.1** | 44.2 | -2.59 | 46 | -6.39 |
| 9 | **41.3** | 44.5 | -7.11 | 44.1 | -6.27 |
| 10 | **42.4** | 46.4 | -8.49 | 46 | -7.73 |
| 11 | **34.8** | 36.9 | -5.61 | 37.74 | -7.71 |
| 12 | **34.6** | 38.9 | -11.1 | 37.8 | -8.54 |

Table (2)

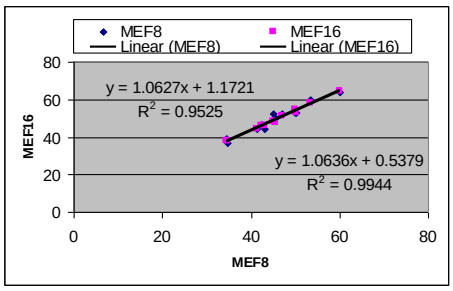


Figure (8)

***3-Effect of time per frame 40, 20 sec on EF;***

The computing of LVEF from 40 & 20 sec per projection of GSPECT for DCP was compared with each other. A good correlation was found between both projection times. Table 3 & Figure 8 shown that the using of 40 sec more accurate for EF estimation than 20sec per projection.

| | REF | MEF (40 sec) | % deff | MEF (20 sec) | % deff |
|---|---|---|---|---|---|
| 1 | 60 | 63.7 | -5.88 | 58 | 3.448 |
| 2 | 53.3 | 60.1 | -11.2 | 57.1 | -6.6 |
| 3 | 50.3 | 53.2 | -5.54 | 50.19 | 0.162 |
| 4 | 50 | 53.1 | -5.9 | 54.6 | -8.42 |
| 5 | 45.6 | 50.2 | -9.3 | 48.39 | -5.82 |
| 6 | 45 | 52.4 | -14.1 | 47.36 | -4.98 |
| 7 | 47 | 52.2 | -9.86 | 52 | -9.52 |
| 8 | 43.1 | 44.2 | -2.59 | 44.39 | -2.99 |
| 9 | 41.3 | 44.5 | -7.11 | 41.49 | -0.39 |
| 10 | 42.4 | 46.4 | -8.49 | 46.7 | -9.11 |
| 11 | 34.8 | 36.9 | -5.61 | 37.88 | -8.05 |
| 12 | 34.6 | 38.9 | -11.1 | 39.2 | -11.8 |

Table (3)

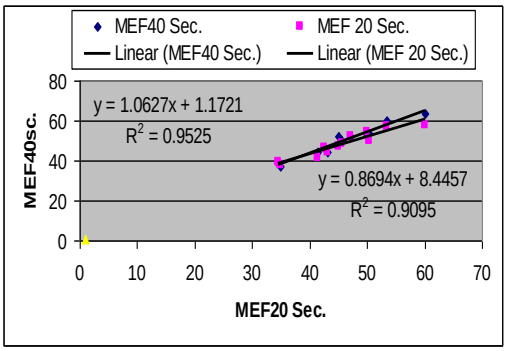


Figure (8)

## IV. CONCLUSION

Gated SPECT is a nuclear medicine imaging method used to evaluate myocardial perfusion using injection of radioisotopes. It is known to be a "gold standard" for volume reconstruction of the heart, and is often used to validate new techniques. Cardiac volumes are computed starting with a set of projection images obtained with a gamma camera; however, results obtained depend slightly on the software parameters used for the reconstruction. A validation using a movable cardiac phantom (MCP) essential to optimize the software parameters, and ensure the accuracy of measurements.

The results obtained with the constructed movable cardiac phantom (MCP) indicate that it's suitable to sample cardiac activity distributions from the balloon coated 99mTc. In case of acquisition parameters study, it's shown that, it's enough to using the 8 frames per cardiac cycle with 40 sec per projection.

## V. ACKNOWLEDGMENTS

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