VALIDATION OF EJECTION FRACTION OBTAINED FROM GATED SPECT IMAGING USING NCAT PHANTOM

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OBJECTIVE: The purpose of this study was to validate the accuracy of three quantification software packages for assessing left ventricular ejection fraction (LVEF) using NURBs-based Cardiac Torso (NCAT) phantom.

MATERIALS AND METHODS: The populations of NCAT phantom with 10 different anatomical heart parameters and 12 different LVEFs were used. The Simulation System for Emission Tomography (SimSET) Monte Carlo simulation code was used to simulate myocardial gated single photon emission tomography (SPECT) projection data with matrix size of 128x128 and 60 views over 180 degrees and gating at 8 frames/cardiac cycles. The projection datasets were reconstructed using ordered subset expectation maximization (OS-EM) algorithm with 6 subsets, 2 iterations and Butterworth filter at cutoff frequency of 0.52 cycles/cm and order of 10. The percentages of LVEF were determined using three quantification software packages; the Emory Cardiac Toolbox (ECTb), 4D-MSPECT and Myovation. Then the accuracy and the correlation of LVEF obtained from each software package were calculated. A two tailed pair t-test was used to test statistically significant differences in LVEFs obtained from 3 packages with p-value <0.05.

RESULTS: The results showed that for LVEF <45%, the percentages of accuracy were 44.59, 11.11 and 54.41 and the correlation coefficients were 0.77, 0.80 and 0.66, while LVEF ≥45%, the percentages of accuracy were 21.06, 7.48 and 15.55 and the correlation coefficients were 0.74, 0.91 and 0.97 for ECTb, 4D-MSPECT and Myovation, respectively. There were statistically significant differences in LVEF (p-value <0.001) among 3 packages.

CONCLUSION: In conclusion, LVEF obtained from 4D-MSPECT was the most accurate and had good correlation with true LVEF for the full range of LVEF. The LVEF obtained from Myovation was less accurate but was well correlated with true LVEF for LVEF ≥45%. While the accuracy of LVEF obtained from ECTb was the least and the correlation with the true LVEF was poor. The LVEFs obtained from 3 software packages were not interchangeable.

Keywords: Ejection Fraction, Gated SPECT, NCAT phantom, Monte Carlo Simulation

The left ventricular (LV) function and myocardial perfusion are the important predictors in nuclear cardiology for diagnosis and prognosis in patients with coronary artery disease (CAD). Myocardial perfusion study has been widely used to determine the adequacy of blood flow to the myocardium, whereas equilibrium-gated blood pool study is widely used for assessment the ventricular

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function such as ventricular volume, ejection fraction (EF), and regional wall motion. Early nuclear cardiology, the assessment of myocardial perfusion and ventricular function were separated. Recently, the development of myocardial gated single photon emission tomography (SPECT) has allowed for the quantitative assessment of LV function simultaneously with the evaluation of the LV perfusion from a single procedure. This development has accelerated the utilization of this procedure for the diagnostic and prognosis associated with CAD. Myocardial gated SPECT has now been routinely used to assess, in addition to myocardial perfusion, global and regional left ventricular function. The main parameter of global function is left ventricular ejection fraction(LVEF).[1-3]

For quantitative analysis of LV functions, several kinds of quantification software packages have been developed and applied to clinical practices. The software packages available in nuclear medicine are the Emory Cardiac Toolbox (ECTb, Emory university, Atlanta, GA), 4D-MSPECT (University of Michigan Medical Center, Ann Arbor, MI) and Myovation (GE healthcare, Haifa). Due to different characteristics of algorithms to determine the LVEF of each software, the same patient could get different LVEFs when different packages were applied. Therefore, the accuracy of three software packages was studied.[4-5]

MATERIALS AND METHODS

Phantom Generation

The NURBs-based Cardiac Torso (NCAT) phantom with various LVEFs developed by Segars[6] was used. Ten different anatomical parameters of male and female hearts were generated. Several parameters were varied to model the realistic variations in the size, shape, orientation and position of the heart (from Emory thorax model database). From each heart model, the ejection fraction of the NCAT phantom was varied from 25% to 75%, in 5% increments.[7] After phantoms were generated, the true LVEFs were computed from the end diastolic volumes and end-systolic volumes. Totally, there were 120 (10x12) NCAT phantoms using this study. Each NCAT phantom was generated in a 128x128x128 array with a pixel size and slice thickness of 0.345 cm. The cardiac cycle of the NCAT phantom was divided into 8 frames.

Gated Projection Data Simulation

Projection data of gated SPECT of each phantom were generated using Simulation System for Emission Tomography (SimSET) Monte Carlo Simulation code[8] and parameterized according to the clinical protocol as followed. A single head thallium activated sodium iodide (NaI(Tl)) detector SPECT system with energy resolution of 9% at 140 keV and a low-energy high resolution (LEHR) collimator with a thickness of 3.5 cm, a hole radius of 0.07875 cm, and a septa thickness of 0.020 cm were used. The radius of rotation was 25 cm and the energy window was set at 20% of 140 keV. The gated projection data were simulated with matrix size of 64 x 64, 60 views over from left posterior oblique (LPO) to 45^0 right anterior oblique (RAO). For gated mode, the cardiac cycle was divided into 8 frames/cycle, the total of projection data was 960 images (8 frames x 60 views). Finally, there were 120 sets of gated projection data used in this study.

Image Reconstruction

Each projection data was reconstructed using the iterative ordered subset expectation maximization (OS-EM) with 2 iterations and 10 angles per subset and this number was used because it gave the most accurate inferior wall thickness. The images were reconstructed into 64x64 arrays with a pixel width and slice thickness of 0.69 cm. The reconstructed images were post-filtered with Butterworth filter with cutoff frequency of 0.52 cycles/cm and order of 10.

Gated SPECT Analysis

To compute the LVEF, three quantification software packages: ECTb, 4D-MSPECT and Myovation on a GE Xeleris workstation were used. The ECTb software uses cylindrical coordinates to sample from the basal wall to the distal wall and spherical coordinates to sample the apex.[9-10] The model for 4D-MSPECT also uses a cylindrical-spherical coordinate system and uses weighted spline and thresholding techniques to refine surface estimates. To estimate wall position and thickness, a gaussian function was used.[11] The Myovation models the heart by automatically detecting the location of center-of-mass left ventricular, a gaussian function was applied to determine the mid-myocardial surface associated with the ellipsoid shape. Then, the endocardial and epicardial surface points were calculated using the standard deviation of a gaussian function. To determine the valve plane, the basal rim of the sampled mid-myocardial was detected. Although all three packages are semi-automatic, all calculations were performed with the default configurations of each package.

Data Analysis

The LVEF of each phantom was determined from three packages and the accuracy of each package was calculated as shown in equation 1.

$$\text{Accuarcy}(\%) = \frac{(\text{LVEF}-\text{LVEF}_{\text{NCAT}})}{\text{LVEF}_{\text{NCAT}}} \quad (1)$$

Furthermore, the linear regression analysis was also applied to determine the correlation of LVEF between those three software packages and the true value from NCAT phantom. For the comparison of the LVEF obtained from ECTb, 4D-MSPECT and Myovation, a two-tailed pair t-test was used to test statistical significant in the mean difference for each pair of software packages.

RESULTS

Table 1 showed the mean, maximum, minimum and standard deviation of the LVEFs obtained from ECTb, 4D-MSPECT and Myovation. The results demonstrated that the average LVEF obtained from ECTb was higher than that from the true value. While the average LVEF obtained from Myovation was lower and the average LVEF from 4D-MSPECT was slightly higher than the true value. Table 2 showed the average accuracies for all ranges of LVEF, LVEF ≥45% and LVEF <45%. The results showed that the overall average accuracies of ECTb, 4D-MSPECT and Myovation, were 30.86%, 8.99% and 31.74%, respectively. For LVEF <45%, the average accuracies of ECTb, 4D-MSPECT, and Myovation were 44.59%, 11.11% and 54.41%, respectively. While LVEF ≥45%, the average accuracies were 21.06%, 7.48% and 15.35% for ECTb, 4D-MSPECT and Myovation, respectively.

Table 1 The mean, standard deviation, maximum and minimum of LVEF for ECTB, 4D-MSPECT and Myovation compared with the true LVEF.

	%LVEF			
	Mean	**SD**	**Min**	**Max**
True Value	47.36	16	20	72
ECTb	59.24	18.30	11	90
4D-MSPECT	48.42	18.60	12	89
Myovation	36.05	21.94	5	80

Table 2 The average of the accuracy of LVEF for ECTb, 4D-MSPECT and Myovation.

LVEF	Accuracy (%)		
	ECTb	**4D-MSPECT**	**Myovation**
All Ranges	30.86	8.99	31.74
<45%	44.59	11.11	54.41
≥45%	21.06	7.48	15.55

The correlation of LVEF between the true LVEF and each software package was studied and divided into two groups: for LVEF <45% and LVEF ≥45%. For LVEF <45%, The correlation between LVEF obtained from ECTb and the true LVEF was shown in Fig.1 and the correlation coefficients was 0.77. Fig.2 showed the correlation between the

LVEF from 4D-MSPECT and the true value with the correlation coefficient of 0.8. The correlation between the LVEF obtained from Myovation and the true LVEF was plotted and shown in Fig.3 with the correlation coefficient of 0.66. The results demonstrated that LVEF obtained from 4D-MSPECT and ECTb were well-correlated and that obtained from Myovation was poor-correlated.

For LVEF $\geq$45%, the correlation coefficients between the LVEF of true LVEF obtained from those three software packages were 0.74, 0.91 and 0.97 for ECTb, 4D-MSPECT and Myovation, respectively. Fig.4 showed the correlation between the LVEF of true LVEF and that from ECTb. The plot revealed that the correlation was poor. While the true LVEFs and that obtained from 4D-MSPECT and Myovation were well-correlated as shown in Fig.5 and 6, respectively.

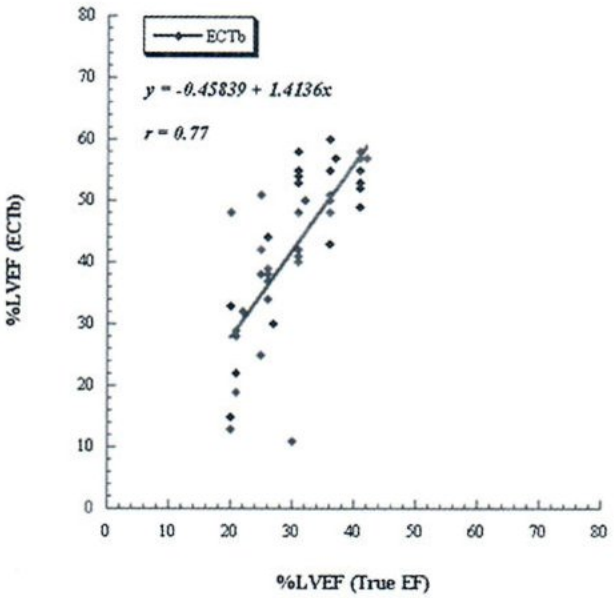

Fig.1 The correlation analysis of LVEF between true LVEF and ECTb for LVEF <45%

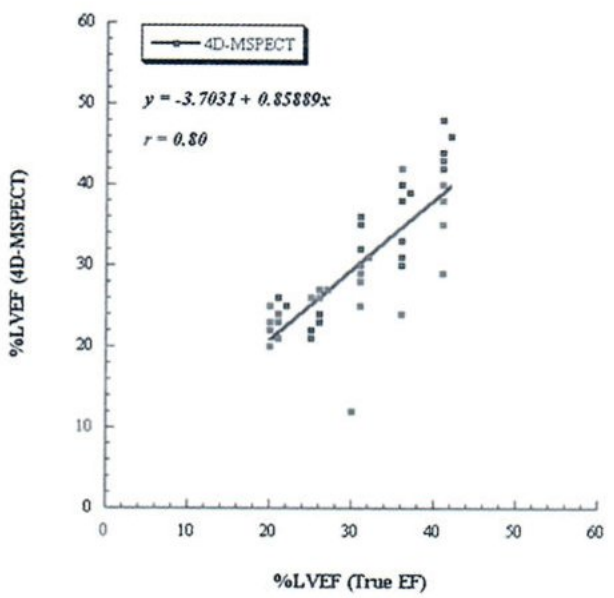

Fig.2 The correlation analysis of LVEF between true LVEF and 4D-MSPECT for LVEF <45%

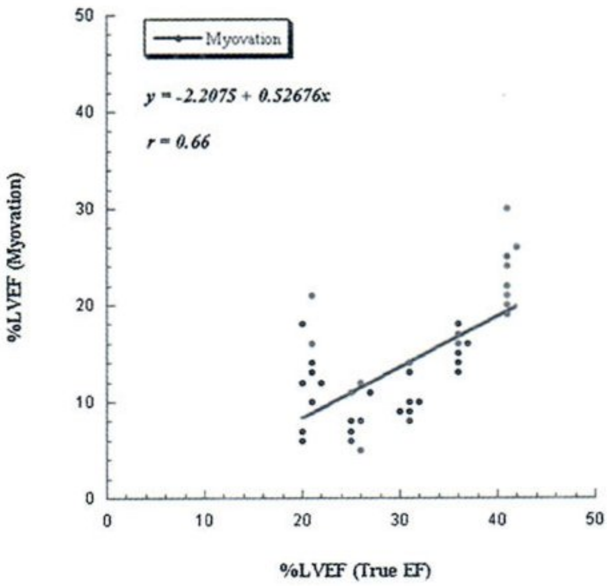

Fig. 3 The correlation analysis of LVEF between true LVEF and Myovation for LVEF <45%

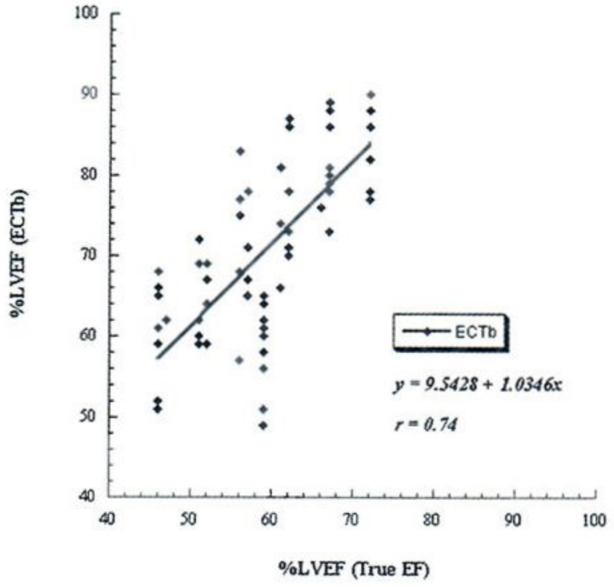

Fig.4 The correlation analysis of LVEF between true LVEF and ECTb for LVEF ≥45%

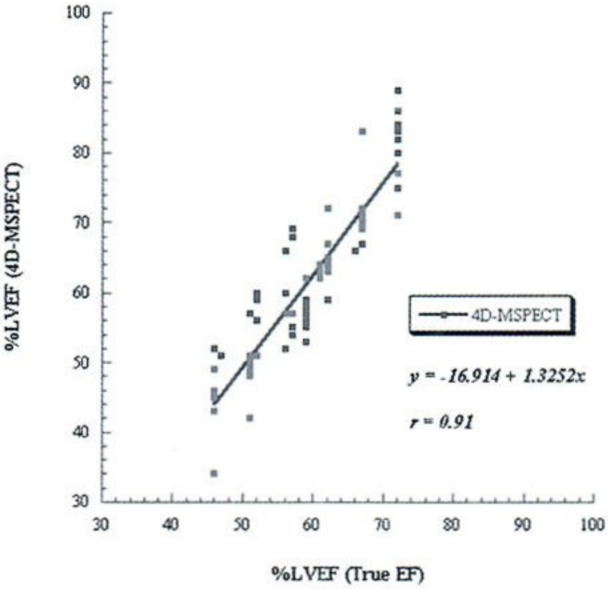

Fig.5 The correlation analysis of LVEF between true LVEF and 4D-MSPECT for LVEF ≥45%

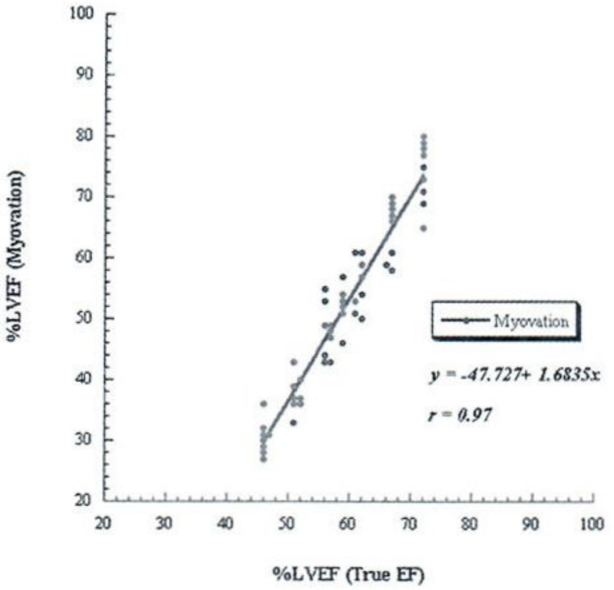

Fig.6 The correlation analysis of LVEF between true LVEF and Myovation for LVEF ≥45%

Table 3 The mean of difference, standard deviation, and p-value for each pair of software packages.

	Mean Difference	SD	P-value
ECTb - 4D-MSPECT	10.83	8.21	<0.001
ECTb - Myovation	23.19	11.34	<0.001
4D-MSPECT - Myovation	12.37	6.81	<0.001

To study the differences between LVEFs obtained from each package, a two-tailed pair t-test was used. Table 3 reported the mean difference of the LVEF, standard deviation and p-value for each pair. The mean difference between LVEF obtained from ECTb and that from 4D-MSPECT was 10.83 and they were statically significantly different with 95% confident interval (p<0.001). The mean difference of LVEF obtained from ECTb and Myovation, was 23.19 and they were statically significantly different with 95% confident interval (p<0.001). Similarly, the mean difference of LVEF obtained from 4D-MSPECT and Myovation was 12.37 and they were statistically significant different with 95% confident interval (p<0.001).

DISCUSSION

From the results of this study, LVEF obtained from 4D-MSPECT was the most accurate than that from the others for all ranges of LVEF. For LVEF <45%, Myovation gave less accuracy than 4D-MSPECT and ECTb. While for LVEF ≥45%, ECTb gave the largest error. The correlation of LVEF between the true LVEF for each software packages was studied using linear regression analysis. The LVEF obtained from 4D-MSPECT was well correlated, the LVEF obtained from ECTb was poor correlated with true LVEF for all ranges of LVEF. The LVEF obtained from Myovation was well correlated with the true LVEF for LVEF ≥45% but poor correlated when LVEF <45%. Schaefer et al.[12] studied the accuracy of QGS, ECTb and 4D-MSPECT in assessment of LVEFs using cMRI as a gold standard. They found that LVEF determined by ECTb, 4D-MSPECT, and QGS from gated ^{99m}Tc-MIBI SPECT agreed over a wide range of clinically relevant values with cMRI. The LVEFs calculated from ECTb and 4D-MSPECT did not differ significantly from cMRI. Nagajima et al.[13] compared the accuracy of LVEFs from 4 software packages: QGS, ECTb, 4D-MSPECT and Perfusion and Functional Analysis for Gated SPECT (pFAST: Sapporo Medical University, Sapporo, Japan) with that from gated blood pool (GBP). They found that all 4 software programs showed well correlations between LVEF and the GBP study. The LVEFs estimated from ECTb and 4D-MSPECT were slightly higher than that obtained from by GBP study. The QGS, ECTb, and 4D-MSPECT gave over estimated LVEF in patients with small hearts.

Although LVEF can be obtained from commercially available software package but the accuracy of LVEF should be considered. The results of this study indicated that the accuracy of LVEF obtained from 4D-MSPECT was high, while that from ECTb was low. The Myovation gave a fairly accurate LVEF. In this study, the accuracy was computed using NCAT phantoms and the heart models of the phantoms might not be exactly similar to the real hearts. However, the results from this study can be used as a guideline for clinician when having follow-up patients that the LVEF should be obtained from the same software packages.

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