Annals of Nuclear Medicine Vol. 18, No. 6, 507–511, 2004

Left ventricular ejection and filling rate measurement based on the automatic edge detection method of ECG-gated blood pool single-photon emission tomography

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The objective of the present investigation was to determine the feasibility of assessing left ventricular systolic ejection and diastolic filling via the automatic edge detection method employing ECG-gated blood pool single-photon emission tomography (SPET GBP) data. ***Methods:*** Thirty-five patients, who had undergone both SPET GBP and ECG-gated equilibrium blood pool scintigraphy by the planar method (planar GBP), were enrolled in this study. Planar GBP was performed with a single-headed gamma camera. From the left anterior oblique projection, data were acquired at 24 frames/cardiac cycle with ECG-gating during the equilibrium state. SPET GBP was conducted utilizing a triple-headed gamma camera, with 60 projection views over 360 degrees by 60 sec per view, in 16 frames/cardiac cycle. In each frame, left ventricular volume was determined by automatic edge detection employing a quantitative gated SPET program. Additionally, the time-volume curve was fitted by the 4th harmonics of Fourier transform. Ejection fraction (EF, %), peak ejection rate (PER, /sec), peak filling rate (PFR, /sec) and mean filling rate during the initial one-third of diastolic time (1/3 FRm) were calculated from the fitted curve. These parameters were also calculated with planar GBP data. ***Result:*** Left ventricular ejection and filling parameters were calculated by SPET GBP with the automatic edge detection program for all patient data. Correlation coefficients of EF, PER, PFR and 1/3 FRm between SPET and planar GBP were 0.91 ($p < 0.001$), 0.82 ($p < 0.001$), 0.78 ($p < 0.001$) and 0.74 ($p < 0.001$), respectively. ***Conclusion:*** Ejection and filling rates can be calculated using SPET GBP with the edge-detection software. These parameters displayed significant correlations with those values obtained via planar GBP. Additional studies are warranted to determine the reliability of parameters with SPET GBP.

Key words: gated SPET, blood pool scintigraphy, ejection fraction, filling rate, ejection rate

INTRODUCTION

LEFT VENTRICULAR systolic ejection and diastolic filling rates sensitively reflect cardiac function; therefore, these parameters can provide beneficial information regarding the pathophysiology of various cardiac diseases.[1–4] In current routine clinical settings, gated equilibrium blood pool scintigraphy by the planar method (planar GBP) is the common approach via which these parameters are obtained.[5]

Electrocardiographic (ECG)-gated myocardial perfusion single-photon emission tomography has become available as a result of recent instrumental developments in computer and multi-detector gamma camera systems. Therefore, the development of automatic analysis programs has facilitated the routine use of these techniques, permitting the assessment of accurate and reproducible

Received March 4, 2004, revision accepted May 19, 2004.
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functional parameters, including systolic ejection and diastolic filling function.[6–9]

ECG-gated tomographic approach can be also available for blood pool scintigraphy. This tomographic approach permits assessment of ventricular function based on three-dimensional data. Therefore, it may be more accurate in the structural separation as compared with conventional planar GBP. An innovative analytical program, BPGS (Cedars-Sinai Medical Center), for ECG-gated blood pool single-photon emission tomography (SPET GBP) calculates ventricular volumes via automatic edge detection.[10] It has been reported that the ejection fraction calculated utilizing BPGS was reproducible and correlated well with that determined by planar GBP.[10–12] Furthermore, BPGS can also yield systolic ejection and diastolic filling rates by calculation of left ventricular volume changes during the cardiac cycle. However, the accuracy of these parameters obtained by BPGS has not been yet assessed. The present study compared these parameters determined via BPGS with those obtained with planar GBP to clarify the feasibility of BPGS with respect to the assessment of ventricular ejection and filling rates.

MATERIALS AND METHODS

Patients

Thirty-five patients (10 females and 25 males), who had undergone both planar and SPET GBP, were enrolled in this study. Patients with arrhythmias were excluded. Age of the participants ranged from 22 to 86 years (mean 50 ± 22). The subject population consisted of 15 patients with suspected angina pectoris, eight displaying old myocardial infarction, five diagnosed with cardiomyopathy, four exhibiting collagen disease and three presenting with valvular disease.

Equilibrium gated blood pool scintigraphy by planar method (Planar GBP)

Red blood cells were labeled with 740 MBq of technetium-99m pertechnetate *in vivo* 15 minutes after intravenous administration of stannous pyrophosphate. Imaging was conducted with a single-headed gamma camera (Orbiter, SIEMENS, USA) equipped with a high-resolution parallel-hole collimator. From the left anterior oblique projection, data were acquired on 64 × 64 matrices by 24 frames/cardiac cycle with ECG-gating during the equilibrium state. Data in cardiac cycles with R-R intervals exceeding ±15% of the average value were excluded. Data analysis was performed on a GMS-550U computer system (Toshiba Medical Co.) utilizing standard software commercially available from the manufacturer. Regions of interest were set over the left ventricle and background on the end-diastolic image. Left ventricular counts were calculated in each frame employing a semi-automatic edge-detection algorithm. Subsequently, a left ventricular time-activity curve and its first derivative curve were generated based on Fourier transforms of the fourth harmonics. Ejection fraction (EF, %), peak ejection rate (PER), peak filling rate (PFR) and mean filling rate during the initial one-third of diastolic time (1/3 FRm) were calculated from the Fourier-fitted curves. PER and PFR were defined as minimum and maximum dV/dt values divided by the end-diastolic volume (/sec). 1/3 FRm defined an average dV/dt value during the initial one-third of the diastolic time (/sec).

ECG-gated blood pool single-photon emission tomography (SPET GBP)

SPET imaging was performed immediately after planar GBP acquisition utilizing a triple-headed gamma camera (GCA 9300/HG; Toshiba Medical Co., Tokyo, Japan) equipped with high-resolution parallel-hole collimators. SPET data were acquired from 60 projections over 360 degrees with 60 sec per view (total acquisition time = 20 min), in 64 × 64 matrices and 16 frames/cardiac cycle with ECG gating. Cardiac cycles with R-R intervals exceeding ±15% of the average value were excluded. A Butterworth filter characterized by a cutoff frequency of 0.50 Nyquist and an eighth order was employed for reconstruction. Reconstructed short-axis tomographic images were processed using the BPGS program; additionally, left ventricular volumes in each frame were calculated. Data were transferred to a personal computer by off-line. The curve convergence was based on Fourier transforms of the fourth harmonics. Subsequently, a left ventricular time-volume curve and its first derivative curve were generated. The parameters of EF, PER, PFR and 1/3 FRm were calculated from the Fourier-fitted curves.

Statistical analysis

Values were expressed as mean ± standard deviation (SD). Correlation between planar GBP and SPET GBP values was assessed by Pearson's correlation coefficient (r). Bland-Altman analysis was utilized to evaluate the bias and to establish the 2SD values between the two studies. The term "limits of agreement" indicates mean ± 2SD.[13] A p value of less than 0.05 was considered statistically significant.

RESULTS

EF, PER, PFR and 1/3 FRm were calculated successfully from the SPET GBP data in all patients assessed by the automatic edge detection program. The difference between heart rate during SPECT imaging and planar imaging was not significant with paired t-test (73.6 ± 13.8 vs. 73.6 ± 13.5, $p = 0.95$). Inter-observer (operator X, Y) reproducibilities of EF, PER, PFR and 1/3 FRm with SPECT GBP were calculated as $Y = 1.0X + 1.7$ ($r = 0.98$, $p < 0.001$), $Y = 0.97X - 0.05$ (where $r = 0.97$, $p < 0.001$), $Y = 1.0X - 0.12$ ($r = 0.96$, $p < 0.001$), and $Y = 1.1X - 0.1$

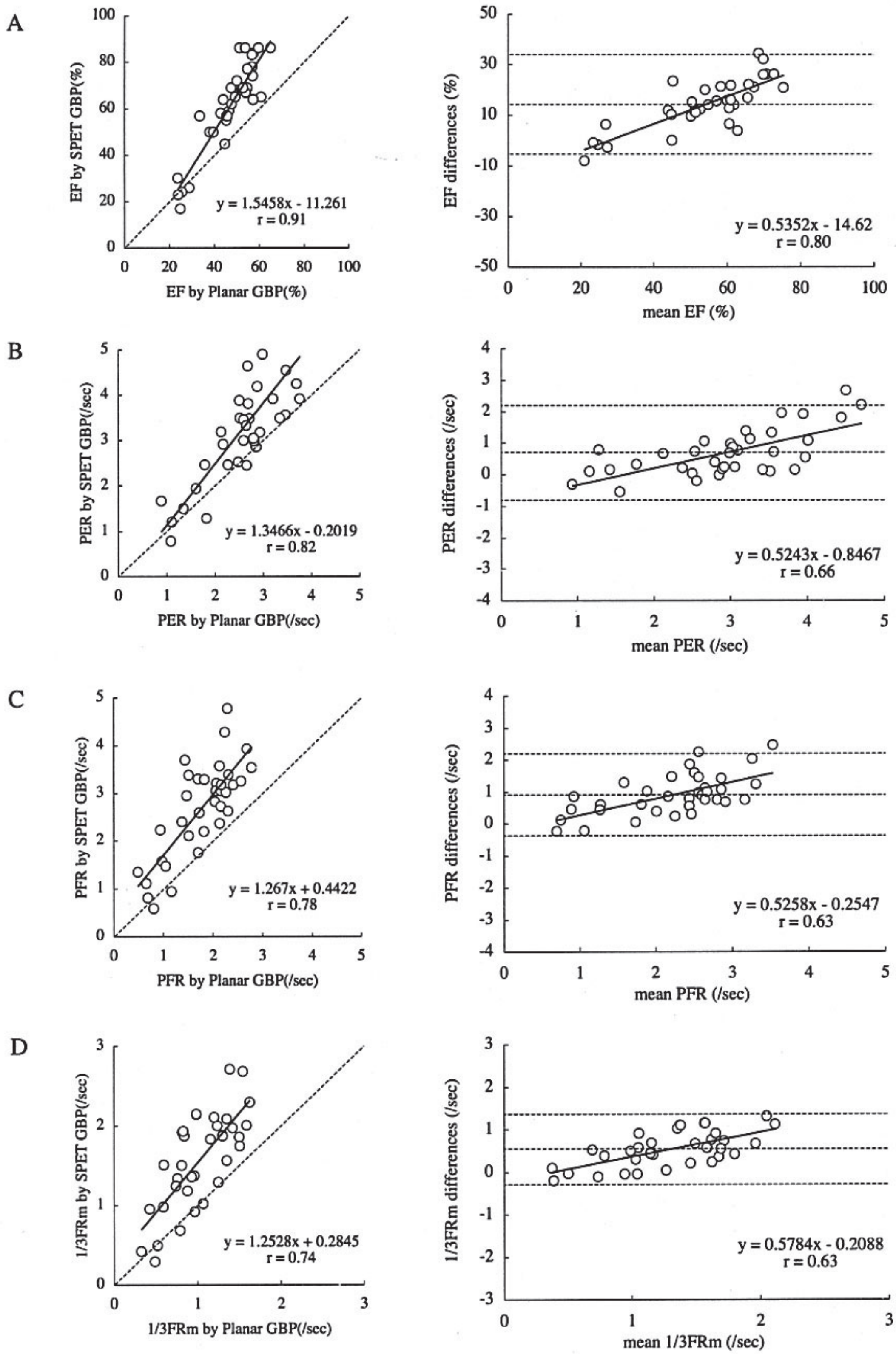

Fig. 1 Comparison of left ventricular ejection fraction (EF) (A), peak ejection fraction (PER) (B), peak filling rate (PFR) (C) and mean filling rate during initial one-third of diastole time (1/3 FRm) between ECG-gated blood pool SPET (SPET-GBP) and planar equilibrium-gated blood pool scintigraphy (planar GBP). Left panels display scatter plots and the results of linear regression analysis; right panels display Bland-Altman plots.

(r = 0.96, p < 0.001), respectively.

Coefficient of regression in EF between SPET GBP and planar GBP was 0.91 ($y = 1.55x - 11.3$: y = EF by SPET GBP, x = EF by planar GBP, $p < 0.001$). The mean difference (EF by SPET GBP − EF by planar GBP) was 14.4% and limits of interval were −5.28 to 34.1%. A significant linear regression was indicated on Bland-Altman plots for EF measurement ($y = 0.54x - 14.6$: y = difference, x = mean, r = 0.80, $p < 0.001$).

Coefficient of regression in PER between SPET GBP and planar GBP was 0.82 ($y = 1.35x + 0.20$: y = PER by SPET GBP, x = PER by GBP, $p < 0.001$). The mean difference (PER by SPET GBP − PER by planar GBP) was 0.70/sec and limits of interval were −0.80 to 2.20/sec. A significant linear regression was indicated on Bland-Altman plots for PER measurement ($y = 0.52x - 0.85$: y = difference, x = mean, r = 0.70, $p < 0.001$).

Coefficient of regression in PFR between SPET GBP and planar GBP was 0.78 ($y = 1.27x + 0.44$: y = PFR by SPET GBP, x = PFR by planar GBP, $p < 0.001$). The mean difference (PFR by SPET GBP − PFR by planar GBP) was 0.91/sec and limits of interval were −0.37 to 2.20/sec. A significant linear regression was indicated on Bland-Altman plots for PFR measurement ($y = 0.53x - 0.25$: y = difference, x = mean, r = 0.63, $p < 0.001$).

Coefficient of regression in 1/3 FRm between SPET GBP and planar GBP was 0.74 ($y = 1.25x + 0.28$: y = 1/3 FRm by SPET GBP, x = 1/3 FRm by planar GBP, $p < 0.001$). The mean difference (1/3 FRm by SPET GBP −1/3 FRm by planar GBP) was 0.55/sec and limits of interval were −0.28 to 1.37/sec. A significant linear regression was indicated on Bland-Altman plots for 1/3 FRm measurement ($y = 0.58x - 0.21$: y = difference, x = mean, r = 0.63, $p < 0.001$).

Systolic and diastolic parameters calculated from SPET GBP displayed significant correlations with those determined from GBP. However, overestimation was observed in all parameters on SPET GBP in comparison with planar GBP; furthermore, all parameters exhibited a significant trend in terms of increased differences with increasing mean values on Bland-Altman plots.

DISCUSSION

The gated SPET technique for blood pool examination could be employed as a standard method due to the development of multi-detector gamma camera and superfast computer systems. This tomographic approach could assess the ventricular volume and shape based on three-dimensional data. Therefore, this methodology is potentially superior to the planar method.[14] However, simple, accurate and fast software is necessary to provide functional parameters for daily practical use. The BPGS software developed at Cedar-Sinai Medical Center is the automatic edge detection program for GBP SPET analysis.[10] Previous examination revealed that EF derived from this program is reproducible and reliable.[12] Our data also demonstrated good reproducibility and satisfactory correlation between SPET and planar GBP in calculating EF. However, SPET GBP tended to overestimate EF in comparison with the planar method, and the overestimation increased with increasing values. The alternative use of SPET and planar GBP should be avoided in follow up examination in a single patient.

In addition to EF assessment, conventional planar GBP yields the systolic and diastolic parameters on the basis of time-activity curves. These parameters sensitively reflect pathophysiology including coronary artery disease.[12,15,16] We developed the method to calculate PER, PFR and 1/3 FRm, in addition to EF, employing SPET GBP with the BPGS program. PER, PFR and 1/3 FRm showed good reproducibility and significant correlation with conventional planar method. However, these correlations were slightly lower compared with those of EF. One factor that may influence the accuracy of the parameters derived from the time-volume curve is the number of R-R intervals for ECG-gating. Generally, a setting of 8 frames per cardiac cycle is utilized for gated-SPET imaging.[8,17,18] This framing is sufficient in terms of EF calculation; however, more accurate time-volume curves derived from increasing the frame number per cardiac cycle may be necessary to calculate ejection and filling rates precisely. Additionally, count intensity affects the accuracy of volume measurement. Insufficient number of counts may cause inaccurate edge detection. Number of R-R intervals for ECG gating is a trade-off for counts in each frame. The acquisition condition consisted of 16 frames per cardiac cycle for ECG-gating in the current investigation, which is the common condition in planar GBP studies. Further investigation involving the number of R-R intervals may be required to define the best values for ECG gating in SPET GBP with respect to calculation of ejection and filling rates.

The ejection and filling rates measured with SPET GBP were also overestimated compared with planar GBP. One of the reasons for these overestimations may be attributable to the BPGS algorithms for edge detection. Another possible factor might be the underestimation of the true values with the planar method, because planar image from the left anterior oblique projection has a slight structural overlap of the atrium and ventricle.

Recently, ECG-gated myocardial perfusion SPET has been widely used to assess left ventricular function. It permits simultaneous evaluation of perfusion and function using automatic edge detection programs. Systolic and diastolic parameters can also be calculated by the method.[9] However, assessment of right ventricular function is impossible, and LV functional evaluation with a large perfusion defect is not feasible by gated myocardial perfusion SPET. SPET GBP method may be advantageous in these situations.

In cine mode display with SPET GBP data, we can observe both left and right ventricle wall motion from a variety of viewpoints without any blind areas. Therefore, the information on regional wall function is more detailed than with the planar method. On the other hand, in calculating functional parameters, the planar method is more simple and easy compared with SPET GBP. However, using automatic analysis program with fast computer systems, it was easy to calculate parameters including filling and diastolic rate and showed good reproducibility.

In conclusion, the ejection and filling parameters can be calculated utilizing edge detection software with SPET GBP. PER, PFR and 1/3 FRm demonstrated good reproducibility and significant correlations with the corresponding parameters obtained from planar GBP.

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