Semiqualitative Visual and Quantitative Morphometric Evaluations of Reduced Scan Time and Wide-Beam Reconstruction in Rest–Gated Stress SPECT Myocardial Perfusion Imaging

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SPECT myocardial perfusion imaging (MPI) now accounts for well over 90% of all MPI studies performed in the United States. A means of reducing the acquisition time while maintaining diagnostic-quality images would be beneficial for both patients and nuclear cardiology clinics. Wide-beam reconstruction (WBR) is a processing algorithm that attempts to address the challenge of obtaining diagnostic-quality images with shorter counting times. This study was designed to incorporate semiqualitative assessments (physician rankings of image parameters) into quantitative assessments (morphologic measurements), as other researchers have done, in an effort to compare filtered backprojection (FBP)—the gold standard—with WBR. **Methods:** Forty-seven MPI studies (from 34 men and 13 women) were masked to 3 physicians who qualitatively rated the images for image quality, myocardial normality, lesion reversibility, and treatment recommendation on a scale of 1–5, with 1 representing "good" and 5 representing "poor." Quantitative values for summed stress scores, summed rest scores, summed difference scores (SDS), end-diastolic volume, end-systolic volume, and the ejection fraction were calculated and reported. **Results:** The semiqualitative analyses of image interpretation indicated that WBR yielded significant improvements over FBP in image quality and showed very good to moderate agreement with FBP among physicians for myocardial normality, lesion reversibility, and treatment recommendation. The quantitative analyses of the morphometric values representing myocardial perfusion, through SDS comparisons, were equivalent for the 2 reconstruction methods. Regression analysis indicated that WBR seemed to underestimate the gated stress–derived FBP ejection fraction by 9%−10%. **Conclusion:** Overall, the WBR method was equivalent or superior to the FBP reconstruction method for MPI with a rest–gated stress same-day protocol in terms of image quality, interpretation, and SDS. Additionally, the advantage of patient comfort derived from shorter imaging times should help reduce motion artifacts and repeat acquisitions as well as enhance patient care and throughput.

Key Words: myocardial perfusion imaging; filtered backprojection; wide-beam reconstruction

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Gated SPECT myocardial perfusion imaging (MPI) has become a powerful tool in nuclear cardiology. SPECT MPI now accounts for well over 90% of all MPI studies performed in the United States. SPECT is superior to the traditional planar technique in terms of image contrast and consequent diagnostic and prognostic yields. However, compared with planar imaging, the SPECT approach involves additional acquisition and processing steps in terms of number of views acquired and tomographic image reconstruction processes, respectively (*1–4*). These additional steps lead to relatively long acquisition times, requiring patient cooperation and other considerations to complete a diagnostic-quality study. A means of reducing acquisition times while maintaining diagnostic-quality images would be beneficial for patients and nuclear cardiology clinics.

Tomographic Reconstruction

SPECT is based on the reconstruction of tomographic images from projection images. Tomographic images are 2-dimensional projections of structures lying within a selected plane of a 3-dimensional patient. A projection image is obtained by positioning a scintillation camera with its plane parallel to the patient's long axis. Tomographic reconstruction theory states that a 3-dimensional image can be backprojected and reconstructed from a series of 2-dimensional projection images acquired at many angles around the patient's body (*5*). As data from each angle overlap the data from other angles, a summation occurs that results in a blurred image, with a loss of resolution and contrast. A mathematic filter applied to this information before it is backprojected

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onto the reconstructed image matrix will recover image contrast and resolution. This reconstruction process is commonly known as filtered backprojection (FBP) (*6*). This process inherently improves contrast by removing underlying and overlying activity but, as with planar imaging, improvements in the resolution characteristics of a SPECT image are made to the detriment of the sensitivity characteristics. Typically, these resolution and sensitivity characteristics depend on the extrinsic camera system, with most of the resolution variations being attributable to the collimator used during the acquisition process (*5*). Although FBP is not the only reconstruction method used in nuclear cardiology, is by far the most widely used.

Iterative Reconstruction

Another reconstruction technique, commonly known as iterative reconstruction, also uses projection images as input but seeks a mathematic solution to the problem of comparing a projection image with an estimated image in the field of view until an agreement is reached. This process is accomplished by considering the value in each pixel of the reconstructed image as an unknown and each point in the profile as an equation. The goal is to determine a mathematic solution to this array of points and equations that represents the reconstructed tomographic image pixel matrix. However, because of the pixel matrix size of a nuclear cardiology image, an iterative approximation approach is used instead. In short, the values of all of the pixels are initially estimated from the FBP data; then, those initial values are slightly altered several times (the "iterations") until they converge to a final result consistent with the available count profiles, ultimately resulting in a reconstructed image. The advantage of using iterative reconstruction techniques is that the resolution and contrast characteristics of the images are typically better than those obtained with FBP. However, the disadvantage is that the acquisition time is equivalent to that of FBP, yet the processing time is intrinsically slower than that of FBP (*4*)—although processing times have been substantially reduced with current computer processors, which operate at gigahertz speeds.

SPECT MPI and Gated SPECT MPI

The acquisition of SPECT MPI studies generally requires a 180° acquisition and an average scan time of 15–25 min. This time requirement often results in patient motion and therefore image artifacts and throughput limitations. Patient motion and organ motion are thought to affect 10%−20% of SPECT MPI studies. Motion artifacts can lead to errors in interpretation (*7,8*), which can have implications for patient care (*3,4*).

The processing of a SPECT MPI or gated SPECT MPI study generally requires appropriate filtering of the projection images, reconstruction of the tomographic transaxial images from the filtered projection images by use of either FBP or iterative reconstruction, and reorientation of the tomographic transaxial images into tomographic short-axis images. Both FBP and iterative reconstruction methods depend on resolution and sensitivity aspects that influence acquisition time; that is, both improve with an increase in acquisition time per step because both are backprojected at some point, and the backprojected image is count dependent for contrast enhancement and noise reduction (*5*).

An alternative to these 2 commonly used methods for image processing that is less dependent on acquisition times and counts is needed. The preferred reconstruction method would be able to reconstruct diagnostic-quality images as effectively as or more effectively than current tools (*9–11*), with shorter counting times to improve patient considerations, minimize motion and subsequent artifacts, and increase throughput.

Alternative Reconstruction Method: Wide-Beam Reconstruction (WBR)

WBR, developed by UltraSPECT, is a processing algorithm that attempts to address the challenge of obtaining diagnostic-quality images with shorter counting times. The theory underlying WBR resolves the resolution–efficiency trade-off (*5*) that is a limiting factor in FBP or iterative reconstruction for SPECT. WBR does not assume that the photons directed at the detector are perpendicular to the detector. WBR uses an iterative image reconstruction process that enables simultaneous resolution and contrast recovery based on modeling of the photon emission and detection process. The model compensates for the beam spread attenuation effects of the collimator and recovers photon data while simultaneously suppressing noise and improving image resolution. The WBR algorithm is optimized for shortened gated MPI stress scans without the application of additional filters (*12–14*).

Several studies have compared the commonly used FBP and iterative reconstruction methods with the UltraSPECT WBR processing algorithm for both phantoms and patients in rest–gated stress SPECT MPI. Oaknin et al. (*14*) reported on a phantom study in which contrast obtained with the half-time acquisition of WBR was compared with contrast obtained with FBP and iterative reconstruction. WBR contrast was 42% higher than that obtained with full-time acquisition and iterative reconstruction for cold spheres and 68% higher than that obtained for hot spheres. In addition, the full width at half maximum resolution measurement was improved from 10.1 mm for FBP to 7.5 mm for WBR. These improvements in resolution and contrast were also noted by Patton et al. (*15*), who reported that WBR increased resolution by 30% over that obtained with FBP. In addition, they reported that the imaging phenomenon of a degradation of resolution with an increase in the distance from the source to the detector was less notable for WBR, with WBR resolution degrading by 0.1 mm with a 1-cm increase in distance and FBP resolution degrading by 0.4 mm with the same increase in distance.

Cantinho et al. (*13*) found no statistically significant differences and strong correlations for the ejection fraction (EF), end-diastolic volume (EDV), and end-systolic volume

(ESV) in a comparison of WBR and FBP in 95 patients. Borges-Neto et al. (*16*) tested WBR and FBP and found no statistically significant differences in summed stress scores (SSS), summed rest scores (SRS), and summed difference scores (SDS) but did note a statistically significant difference for the EF, citing improved resolution as the probable cause. Additionally, Zoccarato et al. (*17*) examined 18 patients who underwent a 2-d ^{99m}Tc-sestamibi protocol. Standard gated SPECT acquisitions at 20 s per frame were reconstructed with FBP (Butterworth). This step was followed by additional gated SPECT acquisitions at half-time (10 s per frame) and WBR. SSS, SRS, and EF were calculated by use of the QGS/QPS program (Cedars-Sinai Medical Center). No significant differences were observed between WBR and FBP for SSS, SRS, and EF, although the EF was 6% lower with WBR than with FBP.

Siegal et al. (*18*) researched the reliability of morphometric data for WBR in comparison with FBP for the EF, EDV, and ESV in 41 patients. Their method involved 22-min gated acquisitions reconstructed with FBP and then 10-min gated acquisitions reconstructed with WBR. The EF, EDV, and ESV were calculated by use of 3 commercial programs (Emory Cardiac Toolbox [Syntermed, Inc.], QGS/QPS, and 4D-MSPECT [Corridor4DM, INVIA]). EFs were found to be comparable for Emory Cardiac Toolbox and QGS/QPS, but a significant difference was found for 4D-MSPECT. In addition, EDV and ESV displayed significant variations for Emory Cardiac Toolbox and QGS/QPS but not for 4D-MSPECT. The authors concluded that the WBR method was as reliable as the FBP method but suggested that each clinical facility should establish normal thresholds for EF comparisons before routine use of WBR.

Although the acquisition times for WBR are generally described to be one half those for FBP, DePuey et al. (*19*) examined the feasibility of reducing the acquisition times further, to one fourth those for FBP. Thirty patients were imaged at full time (25–20 s per step) and then quarter time (6–4 s per step) for rest–stress acquisitions. Full-time studies were processed with FBP and iterative reconstruction. Quarter-time studies were processed with WBR. Image quality was judged with SRS from 1 (“poor”) to 5 (“excellent”). The FBP rest and stress scores were 3.17 and 3.43, respectively, and the iterative reconstruction rest and stress scores were 3.73 and 4.10, respectively. The quarter-time WBR rest and stress scores were 3.33 and 4.10, respectively. Although no statistical analysis was reported, the authors concluded that WBR was equivalent in image quality to iterative reconstruction and superior to FBP. Motion artifacts were noted in 5 of the full-time image sets and in 2 of the quarter-time image sets, providing evidence for the advantage of patient cooperation in association with shorter counting and imaging times.

The empiric equivalence in imaging characteristics, the advantage of shorter scanning times in terms of enhanced patient comfort, the subsequent patient cooperation resulting in less patient motion, and the increased throughput prompted us to perform a comparative analysis of the WBR method of gated SPECT MPI processing with the currently used FBP (Butterworth) method, as suggested by Siegal et al. (*18*), the Intersocietal Commission for the Accreditation of Nuclear Medicine Laboratories (*10*), and the American Society of Nuclear Cardiology (*11*). Because a physician’s interpretation extends beyond the quantitative values described in the processed image summary to include subjective or qualitative impressions from the images themselves, this study was designed to incorporate semiqualitative assessments (physician rankings of image parameters) into quantitative assessments (morphologic measurements), as other researchers have done, in an effort to compare the FBP method—the gold standard—with the WBR method. To conduct this analysis, we addressed the following research questions.

Research Questions

We examined whether there were any significant qualitative differences in perceived image quality, myocardial normality, lesion reversibility, and treatment recommendation between the FBP reconstruction method and the WBR method. In addition, we examined whether there were any significant quantitative differences in SDS and the percentage gated stress left ventricular EF between the FBP reconstruction method and the WBR method.

MATERIALS AND METHODS

Study Protocol

A convenience sample of 47 patients (34 men and 13 women) scheduled for rest–gated stress MPI was selected for this study through consent to undergo 2 imaging periods for the rest and the stress phases of the procedure. The injected ^{99m}Tc-sestamibi doses were based on patient weight, ranging from 259 to 370 MBq (7–10 mCi) for rest and from 777 MBq to ~1.1 GBq (21–30 mCi) for stress. In accordance with the currently accepted American Society of Nuclear Cardiology (*2*) guidelines, each rest study and gated stress study was performed twice with high-resolution collimators and 8 frames per beat. The first scan included the standard acquisition protocol of preset time or beats, 3° per step, a 64 × 64 matrix, and the FBP reconstruction method with a Butterworth filter. The standard rest acquisition protocol was based on full-time scans of 25 s per frame. The standard gated stress acquisition protocol was based on accepted beats per frame, with a value of one half the patient’s heart rate as a guide; for example, if the patient’s heart rate was 70, then the acquisition was set to accept 35 beats per frame. The data were then reacquired at scan times of 15 s per frame (rest) or one quarter the heart rate or a minimum of 15 beats per frame (gated stress) and reconstructed with WBR (the only difference in acquisitions between FBP and WBR was time).

The 47 MPI studies were masked to 3 physicians who qualitatively rated the images for image quality, myocardial normality, lesion reversibility, and treatment recommendation on a scale of 1–5, with 1 representing “good” and 5 representing “poor.”

Five of the 47 MPI studies were not rated by all 3 physicians and therefore dropped from subsequent analysis. The remaining 42 MPI studies (31 men and 11 women) were qualitatively rated by all 3 physicians. Thirty-six of the 42 studies were quantitatively assessed for SSS, SRS, SDS, EDV, ESV, and EF using the QGS/QPS program. We were unable to gate 6 studies, limiting the quantitative reporting of these studies to SSS, SRS, and SDS values.

Analyses

Both semiqualitative and quantitative analyses of the data were planned to answer the research questions and provide a complete review of the utility of WBR. Semiqualitative analyses of the physician rankings of image interpretation for quality, myocardial normality, lesion reversibility, and treatment recommendation included measuring equivalence through repeated-measures χ^2 analysis, percentage agreement calculations, and the Cohen κ statistic for agreement beyond chance. Quantitative analyses for differences in QGS/QPS MPI processing measures of perfusion and ventricular function were based on correlation coefficients and repeated-measures ANOVA of the reported values.

RESULTS

The mean, SD, and median rankings for each of the 4 qualitative variables for each reconstruction method are shown in Table 1. There was some variation in mean rankings between FBP and WBR, but there was no variation in median rankings between the reconstruction methods.

Repeated-measures χ^2 comparisons of physician rankings of processed image quality indicated that physician perceptions of image quality were associated with one image reconstruction method (WBR) over the other (FBP) (χ^2 = 41.9; P < 0.0005). The significant χ^2 association test for image quality across processing method prompted an ex post facto Wilcoxon signed rank test of physician rankings of processed image quality. The Wilcoxon signed rank test confirmed that image quality obtained with the WBR method was rated significantly better than image quality obtained with the FBP reconstruction method (z = 2.1118; P = 0.0174).

Repeated-measures χ^2 comparisons of physician rankings of image interpretation indicated that physician perceptions of the outcome variables myocardial normality, lesion reversibility, and treatment recommendation were not associated with one image reconstruction method over the other ($P \geq 0.05$).

Percentage agreement between FBP and WBR was calculated for the outcome variables myocardial normality, lesion reversibility, and treatment recommendation. The percentage agreement values for the 3 variables were considered to be very good: 84% for myocardial normality, 84% for lesion reversibility, and 83% for treatment recommendation. The 2 reconstruction methods were in absolute agreement for negative outcomes; that is, there was 100% agreement about the most severe predicted outcomes for abnormality, reversible or fixed defect, and need for aggressive treatment.

The Cohen κ values for observed agreement beyond chance alone between FBP and WBR for the outcome variables myocardial normality, lesion reversibility, and treatment recommendation were determined. The κ values were 0.431 for myocardial normality, 0.409 for lesion reversibility, and 0.484 for treatment recommendation. All κ values were significantly different from zero (P < 0.0005), and all were indicative of moderate agreement beyond chance alone between FBP and WBR.

The results of the repeated-measures ANOVA and Pearson correlation coefficient calculations of SSS, SRS, SDS, EDV, ESV, and EF for the reconstruction method comparisons are shown in Table 2. Comparisons of mean SDS indicated no significant difference (F = 0.91; P = 0.3421) and a high correlation (r = 0.8755; P < 0.0005) between the FBP reconstruction method and the WBR method (Fig. 1). EF comparisons indicated that mean FBP EF values were significantly higher than mean WBR EF values (F = 6.13; P = 0.0157) (Fig. 2). The significant differences in mean EF values prompted a regression analysis to verify the relationship between the WBR EF and the FBP EF. This regression analysis resulted in the following equation for the straight line relating the WBR EF to the FBP EF (Fig. 3): FBP EF = 2.1243 + (1.0666 × WBR EF) (t_{70} = 10.5244; P < 0.0005). Although the mean EF values were significantly different, the correlation between the FBP EF and the WBR EF was high (r = 0.8747) and statistically significant (P < 0.0005). The R^2 value, that is, the proportion of the variation in the FBP EF that could be accounted for by the variation in the WBR EF, was 0.7651.

TABLE 1
Descriptive Statistics for Image Interpretation Parameters for FBP and WBR

Reconstruction method (no. of studies)	Image interpretation parameter	Ranking			
		Range	Mean	SD	Median
FBP (42)	Image quality	1–5	2.048	0.8506	2
	Myocardial normality	1–5	2.381	1.497	2
	Lesion reversibility	1–5	2.095	1.353	1
	Treatment recommendation	1–3	1.778	0.9060	1
WBR (42)	Image quality	1–5	1.841	0.7871	2
	Myocardial normality	1–5	2.429	1.500	2
	Lesion reversibility	1–5	2.238	1.500	1
	Treatment recommendation	1–3	1.762	0.9108	1

TABLE 2
Paired Statistics from Repeated-Measures ANOVA and Pearson Correlation Coefficients for SSS, SRS, SDS, EDV, ESV, and Percentage EF by Reconstruction Method (FBP or WBR)

Reconstruction method	Variable analyzed	No. of studies*	Mean	SE	*F*	*P*	Pearson *r*
FBP	SSS	42	2.925	0.8882	0.84	0.3628	0.8618†
WBR	SSS	42	4.075	0.8883			
FBP	SRS	42	0.525	0.2611	0.16	0.6857	0.7999†
WBR	SRS	42	0.675	0.2613			
FBP	SDS	42	2.325	0.7397	0.91	0.3421	0.8755†
WBR	SDS	42	3.325	0.7398			
FBP	EDV	36	67.7	3.5147	6.64‡	0.0121	0.8269†
WBR	EDV	36	80.5	3.5141			
FBP	ESV	36	28.5	2.5659	6.69‡	0.0118	0.8755†
WBR	ESV	36	37.9	2.5661			
FBP	% EF	36	59.97	1.6228	6.13‡	0.0157	0.8747†
WBR	% EF	36	54.06	1.3309			

*Numbers of studies in quantitative and volumetric analyses differed because gating during stress acquisition was not used for 6 patients.
†Significant correlation between FBP and WBR at 0.05 level.
‡Significant difference between FBP and WBR at 0.05 level.

DISCUSSION

Our semiqualitative analyses provided evidence for equivalence in image outcome interpretations between the FBP method (the gold standard) and the investigational WBR method. Further, the WBR method yielded superior image quality, probably because of the higher resolution and contrast of the WBR method than that of the FBP reconstruction method, as noted by both Oaknin et al. (*14*) and Patton et al. (*15*) (Fig. 4). The percentage agreement values and the κ values both indicated that the imaging characteristics myocardial normality, lesion reversibility, and treatment recommendation were found by the 3 reading physicians to be in agreement between the FBP reconstruction method and the WBR method.

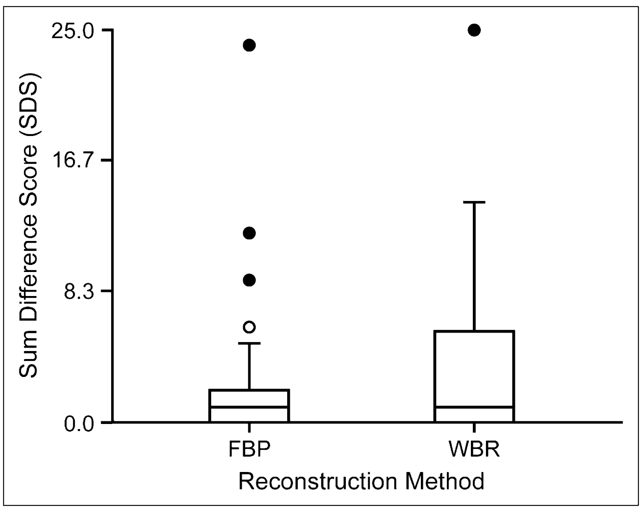

FIGURE 1. Box plot comparing median and distribution of SDS for FBP and WBR. Data indicated no difference between 2 distributions (F = 0.91; P = 0.3421). Whiskers represent 1.5 times the interquartile range. ○ = mild outlier; ● = severe outlier.

Our quantitative analyses confirmed the results of analyses by Cantinho et al. (*13*) and Borges-Neto et al. (*16*) for statistically equivalent SSS, SRS, and SDS. However, our analyses differed from analyses by Siegal et al. (*18*) for the EF. We found a statistically significant difference between the FBP EF and the WBR EF; the WBR method underestimated the FBF EF by ~10%, as predicted by Zoccarato et al. (*17*) and DePuey et al. (*20*). The improvements in image quality described by Oaknin et al. (*14*) as improvements in contrast and resolution should account for the lower EF values because of the enhanced ability to establish left ventricular endocardial and epicardial boundaries during image processing. Recall that the left ventricular EF is calculated from the difference between diastolic and systolic stroke volumes divided by the diastolic stroke volume. Increasing the diastolic and systolic stroke volumes proportionally through resolution improvements with the WBR method would leave the difference between diastolic and systolic stroke volumes essentially the same as with the FBP reconstruction method. However, the EF would then be smaller with WBR because the difference would then be divided by the larger diastolic stroke volume to determine the EF (*20*). Clinical considerations should determine whether this statistically significant difference in the EF is actually clinically significant; however, DePuey et al. (*20*) claimed that the percentage difference would have no meaningful clinical significance, as this difference is no greater than the differences in EF calculated by different programs from different software vendors.

Further, the WBR method would appear to provide clinical benefits by potentially allowing for a reduction in stress SPECT scan times to 50% (or even 25%, as reported

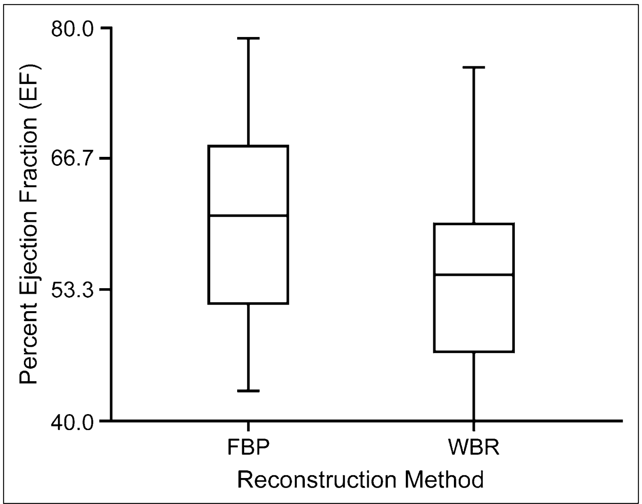

FIGURE 2. Box plot comparing median and distribution of left ventricular EF (percentage) for FBP and WBR. Data indicated significant difference between 2 distributions (F = 6.13; P = 0.0157).

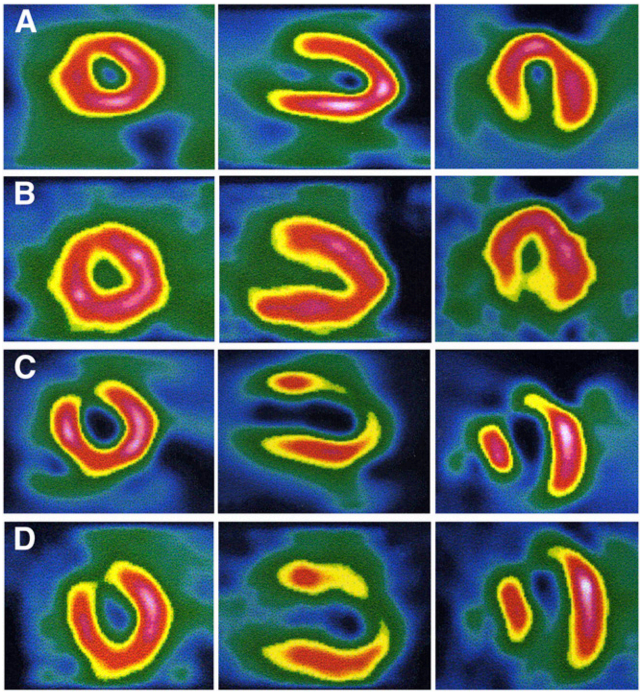

FIGURE 4. Myocardial images in short-axis (left), vertical long-axis (middle), and horizontal long-axis (right) orientations showing normal radiopharmaceutical distribution with WBR techniques (A), normal radiopharmaceutical distribution with FBP techniques (B), abnormal radiopharmaceutical distribution with WBR techniques (C), and abnormal radiopharmaceutical distribution with FBP techniques (D).

by DePuey et al. (*19*)) of the typical clinical scan times without introducing artifacts or deleting useful information. This time reduction aspect should benefit patients by reducing motion artifacts and increasing comfort levels. The benefit for throughput is also evident and should facilitate patient care and scheduling efficiency.

CONCLUSION

Our semiqualitative analyses of image interpretation indicated that WBR yielded significant improvements over FBP in image quality and showed very good to moderate agreement with FBP among physicians for myocardial normality, lesion reversibility, and treatment recommendation.

Our quantitative analyses of the morphometric values representing myocardial perfusion, through SDS comparisons, were equivalent for the 2 reconstruction methods. The WBR method seemed to underestimate the gated stress–derived FBP EF. Regression analysis indicated that this underestimate was usually within 9%–10% of the FBP EF. Clinical considerations should determine whether this difference is clinically significant.

Overall, the WBR method is equivalent or superior to the FBP reconstruction method for MPI with a rest–gated stress same-day protocol in terms of image quality, interpretation, and SDS. Additionally, the advantage of patient comfort derived from shorter imaging times should help reduce motion artifacts and repeat acquisitions as well as enhance patient care and throughput.

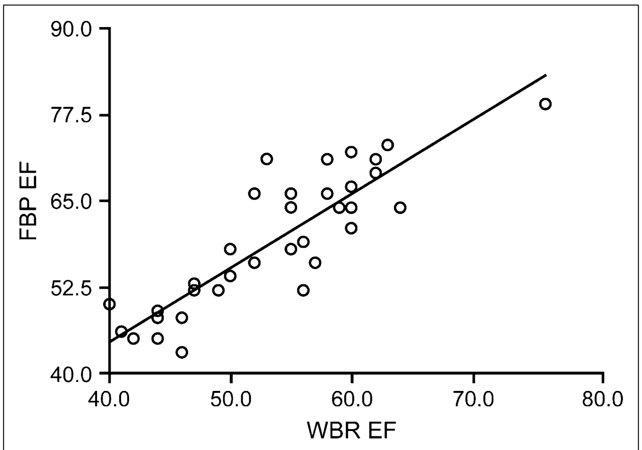

FIGURE 3. Linear regression plot indicating relationship between FBP EF and WBR EF. Equation describing plot was as follows: FBP EF = 2.1243 + (1.0666 × WBR EF).

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