Comparison of Image Quality, Diagnostic Accuracy, and LV Parameters in Filtered Backprojection Versus Iterative SPECT Reconstruction in Myocardial Perfusion Scintigraphy

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ABSTRACT

Background:

Myocardial perfusion scintigraphy images with iterative reconstruction showed higher qualitative and quantitative estimates.

Objective:

This study was conducted to compare image quality, diagnostic accuracy, and LV parameters with standard FBP versus OSEM as baseline quality assurance for the choice of reconstruction algorithm most applicable in the local setting.

Methods:

This was a retrospective cross-sectional study of 55 Thallium-201 (Tl-201) scans and 14 Techentium-99m sestamibi (Tc-99m) images that were reprocessed with filtered backprojection (FBP) and with ordered subset expectation maximization (OSEM). The image quality, diagnostic accuracy, and LV parameters of both SPECT reconstructions were compared.

Results:

OSEM reconstruction resulted in a significantly smooth background tracer activity as opposed to the standard FBP in both Tl-201 (p<0.01) and Tc-99m (p=0.01) scans. Distinct LV border was superiorly seen in OSEM. There was no significant difference in the diagnostic accuracy between the two reconstruction parameters despite 2 cases of interpretation discrepancies. End-diastolic volume generated by OSEM was significantly higher (117.60+55.14 vs 118.51+55.11, p<0.01 in Tl-201 and 101.07+75.58 vs 104.29+80.39, p =0.01 in Tc-99m). With Tc-99m scans the end-systolic volume and ejection fraction in OSEM were likewise significantly different from FBP (p=0.04 and p<0.01, respectively).

Conclusion:

OSEM reconstruction offers smooth background tracer activity with comparable diagnostic accuracy to FBP. All the LV parameters in OSEM were significantly different from FBP in Tc-99m scans and only the EDV in thallium images.

***Keywords**: iterative reconstruction, FBP, image quality*

INTRODUCTION

Single photon emission computed tomography (SPECT) is a widely accepted imaging modality for the evaluation of myocardial ischemia and viability. Good image quality is fundamental in increasing its diagnostic accuracy. One of the factors affecting the final tomographic image, other than detection efficiency and spatial resolution of collimator-detector system, is the reconstruction algorithm [1,2].

Filtered backprojection (FBP) has been the standard SPECT image reconstruction because it is fast, simple, and computer memory efficient. In the process, a ramp filter is applied to suppress statistical noise, which usually has the same frequency as the true myocardial data. This initial step leads to smoothed/blurred image that may potentially disguise small, mild defects [3]. Thus, other techniques like iterative reconstruction (IR) was developed. Maximum Likelihood Expectation Maximization (MLEM) reconstruction is performed in an iterative fashion, with updates based on comparison with measured estimated projection data. This method reduces streak artifacts found in FBP reconstruction. Eventually, with higher speed computers Ordered Subset Expectation Maximization (OSEM) has become the method of choice, whereby only a subset of the projections are used in each iteration, allowing more rapid and accurate data convergence [4]. Also IR became the requirement for scatter and attenuation corrections, and resolution recovery which can mitigate artifacts in the imaging process.

In May 2010, the American Society of Nuclear Cardiology (ASNC) recommended IR for SPECT processing, since image quality comparable to FBP can be obtained with as little as 50-70% of the counts. Since the detected count density is dependent on the injected radioactivity, IR technique holds the promise of significantly reducing administered dose and patient radiation exposure [5] This study was conducted to compare image quality, diagnostic accuracy, and left ventricular (LV) parameters with standard FBP versus OSEM as baseline quality assurance for the choice of reconstruction algorithm most applicable at the local setting.

General Objective:

To determine the clinical utility of OSEM reconstruction versus standard FBP in detecting CAD.

Specific objectives:

To evaluate and compare image quality using FBP and OSEM

To determine the validity of FBP and OSEM in detecting CAD using coronary angiogram as reference standard

To compare LV parameters generated with FBP and OSEM

METHODOLOGY

This was a cross sectional study of technetium-99m (Tc-99m) and thallium-201 (Tl-201) myocardial perfusion scintigraphy (MPS) from 2010 to 2013 done at Nuclear Medicine Division of Philippine Heart Center. Patients 19 years old and above with coronary angiogram done within 6 months of MPS and with no intervening cardiac events were enrolled in the study. Eligible patients were excluded if with history of myocardial infarction and/or revascularization procedure and those with submaximal treadmill exercise (peak maximal heart rate for age <85%).

Myocardial Perfusion Scintigraphy

Patients who underwent MPI were advised of at least four hours fasting with cessation of beta-blocker, calcium -channel antagonist, smoking, and caffeine for 24 hours, and nitrates for 4 hours prior to procedure. For Tc-99m sestamibi using one-day protocol, resting scan was performed 30 minutes after intravenous administration of 8-9 mCi followed by stress imaging through treadmill exercise or dipyridamole (0.57 mg/kg) 15-30 minutes after injection of 24-27 mCi. For Tl-201, imaging commenced after administration of 3 mCi at peak exercise or hemodynamic response to dypiridamole with delayed imaging done after 4 hours.

The data were acquired by a rotating dual-head gamma camera Jetstream Autospect Plus software (Philips Medical Systems, MA, USA) equipped with a low energy, vertex general-purpose collimator connected to a dedicated computer system. The detectors were set in L-mode or 90o configuration. Thirty-two projections were obtained over a semicircular arc, 450 right anterior oblique to 45o left posterior oblique position, in a step-and-shoot manner, with 20% symmetric energy window centered at 140-keV peak for technetium and 68 keV peak for Tl-201, matrix size of 64 x 64 x 16. The time/projection for Tc-99m sestamibi was of 25 sec/frame for rest and 20 sec/frame for stress and, for thallium-201 was 40 sec/frame for rest/redistribution scan and 50 sec/frame for delayed imaging done the following day. Projection profiles were initially reconstructed using filtered backprojection (FBP) and then with ordered subset expectation maximization (OSEM). SPECT reconstruction parameters were as follows :

Controls	FBP	OSEM
Start		Uniform
Iterations		Tl-201 – 2 Tc-99m – 6
Subsets		Tl-201 – 2 Tc-99m – 4
Filter	Butterworth	Butterworth
Cut-off	Tl-201 Rest – 0.45 Stress – 0.50 Tc-99m Rest – 0.66 Stress – 0.55	Tl-201 Rest – 0.45 Stress – 0.50 Tc-99m Rest – 0.66 Stress – 0.55
Order	5	5
Zoom	1.46	1.46
Motion	None	None
Attenuation	None	None

Outcome Data

A. Image Quality

Two nuclear medicine experts separately assessed on screen the image quality (Appendix A) and the perfusion status of SPECT reconstructed images using FBP and OSEM. They were blinded with the reconstruction parameter, patient's clinical data, and coronary angiogram result. The senior consultants' reading was used for the analysis. Superior image quality should have smooth background activity, distinct LV border, and is not degraded by presence of common normal variations and technical artifacts.

B. Diagnostic Accuracy

Using a 17-segment model, a visual perfusion analysis was done and those with abnormal perfusion findings (ischemia, partial thickness fibrosis and infarct) were considered positive for coronary artery disease (CAD), defined as >50% left main stenosis and/or >70% coronary artery stenosis. Patients whose angiogram result was normal, with luminal irregularities, and with borderline lesions of functionally insignificant stenosis were considered CAD-free .

C. Coronary Angiogram

Results of coronary angiography done using standard technique within 6 months, before or after perfusion scintigraphy at the clinical discretion of the referring physician, will be retrieved. Cine angiograms of the coronary obtained in multiple projections using Philips Allura SD 20 and Philips Allura SD 10/10 were included in the study.

D. Left ventricular parameters

Both FBP and OSEM software generated left ventricular end-diastolic volumes, end-systolic volumes and ejection fraction (AutoQuant 6.5, QGS; Cedars-Sinai Medical Center) were compared.

Waiver of Consent

The study shall be conducted in compliance with the ethical principles set forth in the Declaration of Helsinki. Prior to the study, the protocol shall be reviewed and approved by the Philippine Heart Center Institutional Ethics Review Board (PHC IERB). The investigator requested for the waiver of informed consent for the risk to the subject's privacy is minimal and no sensitive information will be obtained. The investigator also ensured that the subject's anonymity is maintained.

Sample Size

Using Epi Info version 7 software, the minimum sample size requirement was estimated to be at least 70 using the following parameters: alpha of 5%, FBP sensitivity of 95.24% in detecting CAD based on the study of Won et al., and with maximum tolerable error of 10%.

Statistical Analysis

Data analysis was done using Stata SE version 13. Quantitative variables were summarized and presented as mean and standard deviation, while qualitative variables will be tabulated and presented as frequency and percent distribution. Comparison of image quality between FBP and OSEM was done using McNemars test while comparison of LV parameters was performed by using dependent t —test. The sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV) of FBP and OSEM in detecting CAD using coronary angiography as the gold standard were determined with 95% confidence level.

RESULTS

Fifty-five Tl-201 (11, normal coronaries; 20, 1-vessel disease (VD); 10, 2-VD; 14, 3-VD) and 14 Tc-99m (2, normal coronaries; 6, 1-vessel disease (VD); 2, 2-VD; 4, 3-VD) scans with adequate stress and rest projection counts were evaluated in both FBP and OSEM reconstructions. Patient's demographics showed mean age of 59-60 years old, obese, predominantly males, and with risk factors for CAD as reflected in Table 1.

Image Quality

OSEM reconstruction resulted in a significantly smooth background tracer activity as opposed to the standard FBP as seen in Table 2. With the other image quality parameters, no significant difference was noted in terms of the LV borders (with/without extracardiac activity) and technical variations in both radiopharmaceuticals.

As with Tl-201 scans, there was smooth background activity with OSEM reconstruction than with FBP (Figure 1).

Although thallium images with OSEM and FBP had equally distinct LV borders, there was superior image quality noted in OSEM reconstruction (Figure 2).

The smoothness in background tracer activity offered by OSEM in Tl-201 scans was all across vessel disease; however, distinctness of LV borders diminishes with increasing number of vessel disease (Figure 3).

OSEM and FBP reconstructions in Tc-99m scans revealed equally superior image quality including the distinctness of LV myocardium, and the absence of technical and anatomic variations as shown in Figure 4.

As shown in Figure 5, in Tc-99m scans there was smooth background activity OSEM reconstruction than with FBP.

Diagnostic accuracy

The diagnostic accuracy of OSEM for CAD was similar to FBP in both Tl-201 and Tc-99m scans as depicted in Table 3.

In thallium, there were only 2 instances where change of interpretation was made but still read as abnormal. FBP had 1 segment ischemia while OSEM had 2. The other case was FBP with partial thickness scar (PTS) with ischemia while OSEM had PTS with viable myocardium. In the latter case, both interpretations will not alter the benefit of revascularization to the patient.

TABLE 1. Baseline characteristics of patients in the study

Characteristics	Thallium (n=55) X ±SD or n (%)	Tc-99m sestamibi (n=14) X±SD or n (%)
Age, years	59.23 ± 10.22	60.57 ± 7.22
Female	14 (29.17%)	4 (28.57%)
Body mass index (kg/m^2)	25.49 ± 4.07	26.74 ± 4.30
Abdominal circumference (inc)	35.77 ± 3.92	36.2 ± 4.02
Risk factors		
Hypertension	38 (86.36%)	13 (92.86%)
Diabetes mellitus	17 (38.64%)	6 (42.86%)
Dyslipidemia	29 (69.05%)	13 (92.86%)
Smoking	21 (51.22%)	4 (28.57%)
Projection stress counts	2830599 ± 584486.7	21250145.79 ± 8512354.69
Projection rest counts	2281029 ± 373724.9	15400009.86 ±14330220.41

TABLE 2. Image quality assessment on FBP and OSEM in Tl-201 and Tc-99m scans

Radiopharmaceuticals	Thallium-201			Tc-99m sestamibi		
Image Quality Parameters	**FBP**	**OSEM**	**p-value**	**FBP**	**OSEM**	**p-value**
Smooth background activity	2	52	<0.01	6	14	0.01
Distinct LV borders	30	32	0.50	14	14	1.00
Preserved LV borders in adjacent extra-cardiac tracer activity	42	42	1.00	13	13	1.00
Absence of						
Basal septum dropout	46	45	1.00	6	6	1.00
Apical thinning	43	43	1.00	8	8	1.00
Brighter lateral wall than septum	45	45	1.00	13	13	1.00
Anterior wall attenuation	48	49	1.00	10	10	1.00
Inferior wall attenuation	35	38	0.25	11	11	1.00
Motion artifact	49	49	1.00	14	14	1.00

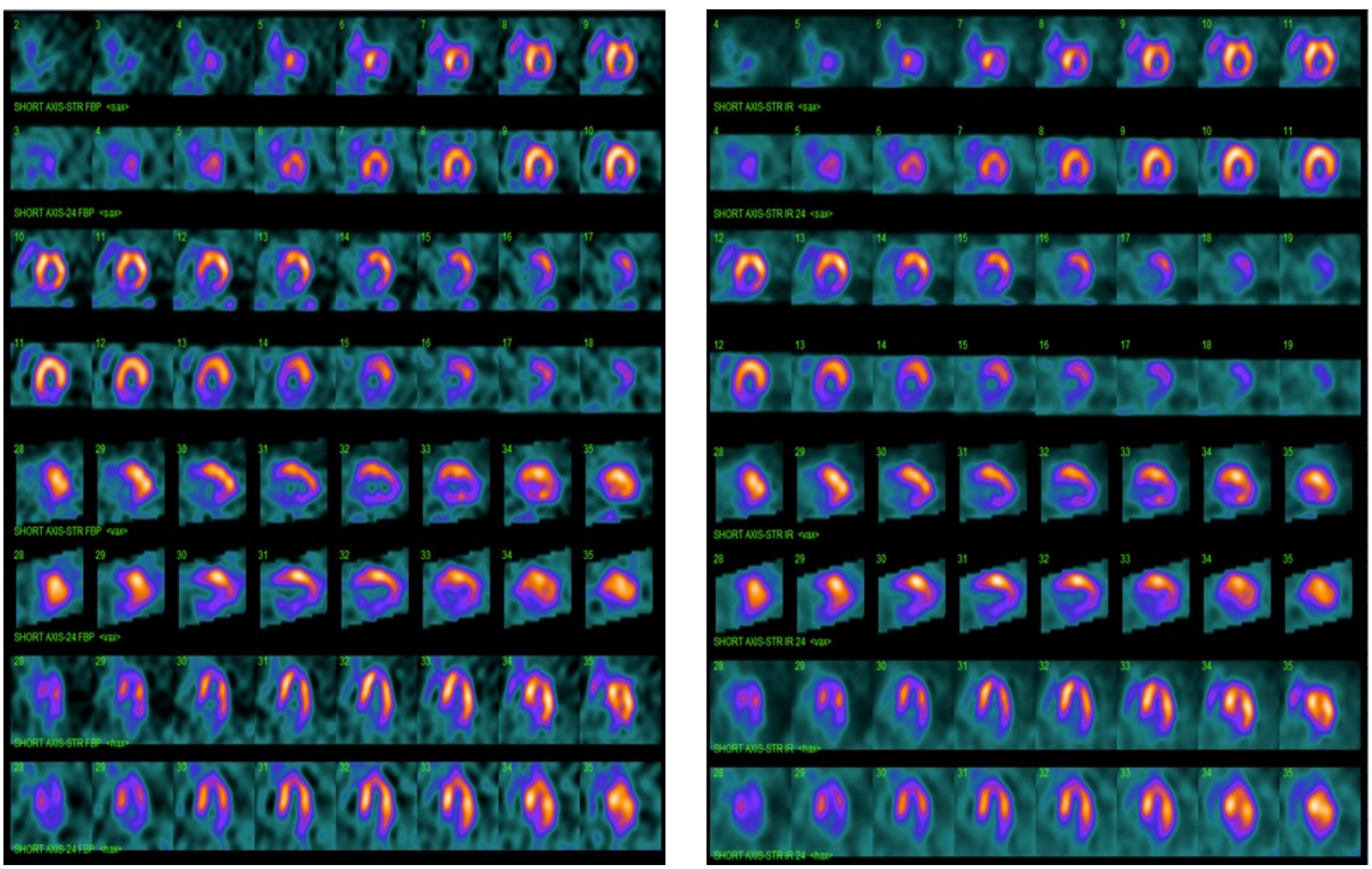

FIGURE 1. Thallium scan of the same patient reprocessed with FBP (left) and OSEM (right).

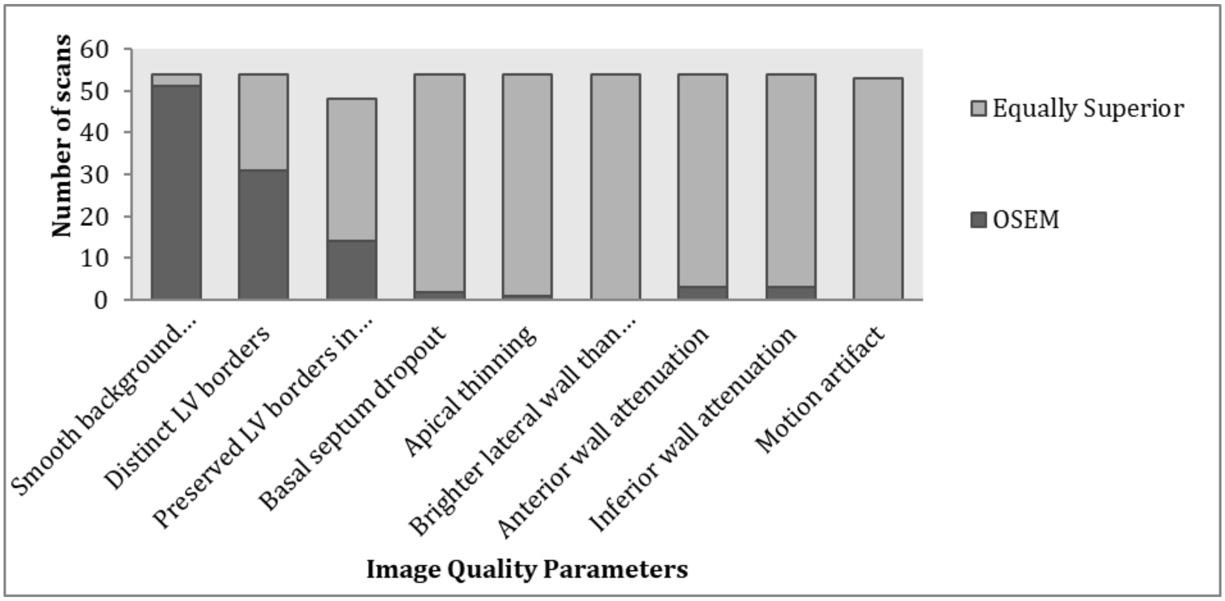

FIGURE 2. Number of Tl-201 scans with superior image quality

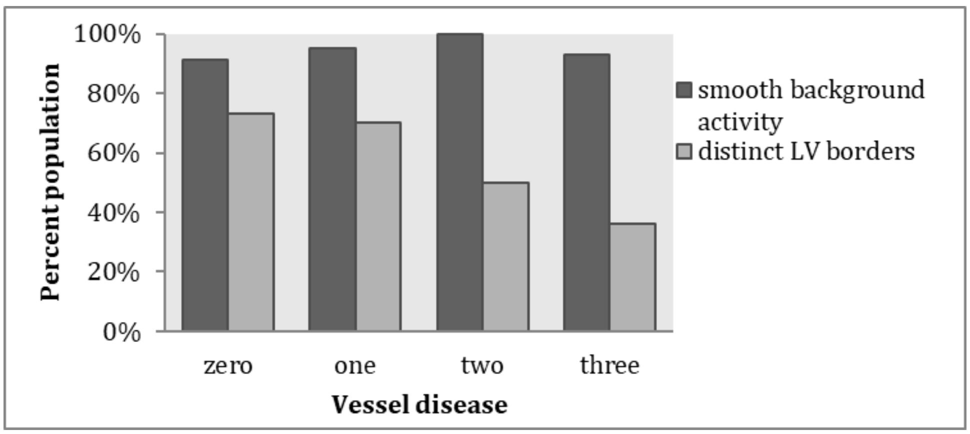

FIGURE 3. Percent population of OSEM processed Tl-201 scans by vessel disease having smooth background tracer activity and distinct LV borders.

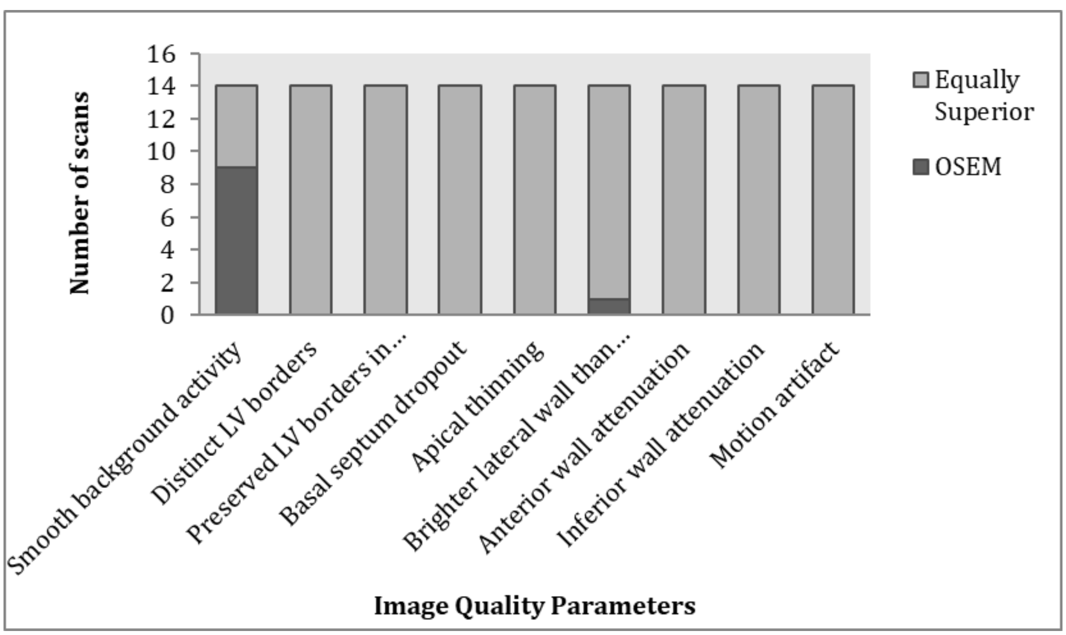

FIGURE 4. Number of Tc-99m scans with superior image quality

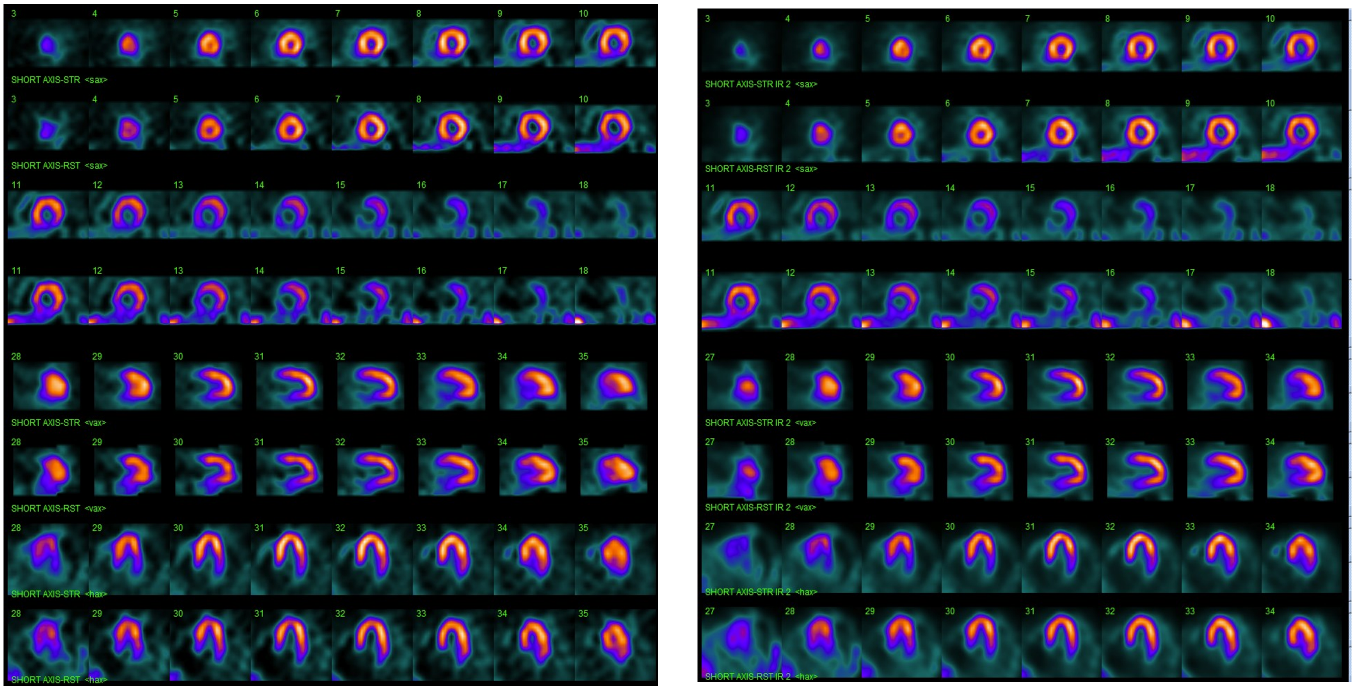

FIGURE 5. Tc-99m scan of the same patient reprocessed with FBP (left) and OSEM (right).

TABLE 3. Diagnostic accuracy of FBP and OSEM in detecting CAD in Tl-201 and Tc-99m

Radiopharmaceutical	Thallium-201		Tc-99m sestamibi	
SPECT reconstruction	**FBP**	**OSEM**	**FBP**	**OSEM**
Sensitivity	75.00%	75.00%	66.67%	66.67%
Specificity	77.42%	77.42%	87.50%	87.50%
Positive predictive value	72.00%	72.00%	80.00%	80.00%
Negative predictive value	80.00%	80.00%	77.78%	77.78%

TABLE 4. Left ventricular parameters of FBP and OSEM with Tl-201 and Tc-99m scans

LV Parameters	FBP	OSEM	p-value
Thallium-201			
End-diastolic volume (EDV) in mL	117.60±55.14	118.51±55.11	<0.01
End-systolic volume (ESV) in mL	67.78±52.67	68.25±52.40	0.09
Ejection fraction (EF) in %	48.49±17.59	48.51±17.42	0.87
Tc-99m sestamibi			
End-diastolic volume (EDV) in mL	101.07±75.58	104.29±80.39	0.01
End-systolic volume (ESV) in mL	47.79±37.92	49.57±36.89	0.04
Ejection fraction (EF) in %	57.79±13.00	57.00±13.24	<0.01

Without the advantage of a known coronary angiogram result, 2 cases of mild hypoperfusion in segments with borderline stenosis were read as attenuation in both OSEM and FBP reconstructions.

LV parameters

In Tl-201 there was statistical difference only in the end-diastolic volumes (EDV) generated by the two SPECT reconstruction methods. However, with Tc-99m studies, all LV quantifications generated from OSEM was significantly different from that of FBP processing (see Table 4).

Inter-observer variability

In Tl-201, the subjective variability with FBP in terms of the absence of basal septum dropout, apical thinning, brighter lateral wall, and inferior wall attenuation was likewise noted in OSEM (Table 5). However, with OSEM there was significant difference in the absence of anterior wall attenuation appreciated by the readers.

With Tc-99m scans, only the absence of apical thinning and inferior wall attenuation has significant variability in both FBP and OSEM (Table 6). The smooth background activity, however, was variable only in the OSEM reconstruction.

The inter-rater variabilities in both Tl-201 and Tc-99m scans may be due to the differences in the visual threshold of the readers and probably learning curve time since both readers were not experienced with OSEM reconstructed images.

DISCUSSION

This study showed that with OSEM, there was significantly smooth background tracer activity and significantly higher EDV in both thallium and technetium scans as compared with the standard FBP reconstruction.

The principle behind iterative reconstruction is the repeated process of updating the actual SPECT projection profile to achieve good data convergence with the measured information. By using uniform flood field as initial estimate, we eliminate ramp filters that predominantly carry statistical noise. This results to smooth tracer distribution and thus improving image contrast.

However, increasing the number of iterations likewise increases noise generation, which was evident in low count studies such as Tl-201. By keeping the subset and iteration at a minimum, we managed to produce thallium scans with smooth background activity and more distinct LV myocardial borders that is not degraded by attenuation and motion artifacts. This is of great advantage to scans of severe CAD where increased lung tracer activity from severe LV dysfunction may result to a noisy background tracer distribution. Kadrmas [6] performed one of the few studies with thallium and they reported a lower noise level with iterative reconstruction -based scatter correction compared with scatter subtraction methods.

Owing to the high photon flux nature of technetium scans, a wider range for iterations and subsets may be applicable prior to image degradation. Forward investigations with IR were mainly carried out with Tc-99m due to a more flexible protocol including dosing and acquisition times. Our findings were similar to the reported studies of comparable image quality and diagnostic accuracy of OSEM to FBP done by Won et al. [7] and Kedziora et al. [8]. But if IR is incorporated with scatter compensation, attenuation correction, and resolution recovery it provided significantly better detection accuracy than FBP in spite the extra clinical nuclear imaging information normally available [9] Furthermore with wide beam reconstruction even with half-time OSEM, there was significantly improved diagnostic quality compared with full-time FBP [10] and even quarter-time OSEM was comparable to full-time OSEM [11]. With motion artifact, Hatton et al. [12] revealed that in the absence of any attempt to correct for missing projections, OSEM reduced the influence of artifacts compared to FBP. However, Zakavi et al. [13] reported that OSEM was less tolerant to motion artifact. In our study, there was no significant difference in the motion artifact observed in both OSEM and FBP may it be in thallium or Tc-99m scans.

Better image contrast with sharper LV myocardial border definition in OSEM than FBP may explain the significantly higher EDV observed in the study. A research study using a beating-heart phantom revealed that OSEM reconstruction presents better estimations of the LV quantitative parameters than FBP [14].

TABLE 5. Interobserver variability on image quality assessment using FBP & OSEM in Tl-201

SPECT Reconstruction	FBP			OSEM		
Image Quality Parameters	**Reader 1**	**Reader 2**	**p-value**	**Reader 1**	**Reader 2**	**p-value**
Smooth background activity (n=55)	2	4	0.69	52	53	1.00
Distinct LV borders (n=55)	30	32	0.81	32	52	0.00
Preserved LV borders in adjacent extra-cardiac tracer activity (n=46)	42	40	0.69	42	42	1.00
Absence of						
Basal septum dropout (n=53)	46	15	<0.01	44	15	<0.01
Apical thinning (n=50)	40	28	<0.01	40	28	<0.01
Brighter lateral wall than septum (n=49)	41	28	<0.01	41	28	<0.01
Anterior wall attenuation (n=50)	45	40	0.06	46	40	0.03
Inferior wall attenuation (n=52)	34	23	0.02	37	25	0.01
Motion artifact (n=52)	49	46	0.51	49	49	1.00

TABLE 6. Interobserver variability on image quality assessment using FBP & OSEM in Tc-99m

SPECT Reconstruction	FBP (n=14)			OSEM (n=14)		
Image Quality Parameters	**Reader 1**	**Reader 2**	**p-value**	**Reader 1**	**Reader 2**	**p-value**
Smooth background activity	6	4	0.63	14	8	0.03
Distinct LV borders	14	11	0.25	14	12	0.50
Preserved LV borders in adjacent extra -cardiac tracer activity	13	9	0.13	13	11	0.50
Absence of						
Basal septum dropout	6	10	0.22	6	10	0.22
Apical thinning	8	2	0.03	8	2	0.03
Brighter lateral wall than septum	13	13	1.00	13	13	1.00
Anterior wall attenuation	10	9	1.00	10	9	1.00
Inferior wall attenuation	11	2	<0.01	11	2	<0.01
Motion artifact	14	13	1.00	14	13	1.00

CONCLUSION

OSEM reconstruction offers smooth background tracer activity with comparable diagnostic accuracy to standard FBP. There was significantly higher EDV with OSEM in both thallium and Tc-99m scans .

Limitations

Small sample size of Tc-99m scans. LV parameters were not correlated with 2D echo findings

Recommendations

With the improved image contrast offered by iterative reconstructions, other analytical reconstruction like Astonish, which incorporates scatter and attenuation correction, and resolution recovery in half-time projection acquisition warrants investigation with the aim of reducing the acquisition time to ease patient motion and to the increase volume of scans per day.

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