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Effects of Various Filters on Image Quality and Other Image Parameters in TC99m Sestamibi Myocardial Perfusion Spect Imaging

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ABSTRACT

Introduction: To reduce statistical noise and produce optimum images of clinically acceptable qualities, filters are used in nuclear medicine imaging. Myocardial perfusion imaging (MPI) using Tc-99m sestamibi in SPECT/CT is used to ascertain viability of myocardial cells by assessing its physiological functioning.

Materials & Methodology: Cardiac SPECT studies using TC-99m sestamibi (740-925) MBq was conducted in 20 patients referred to department of Nuclear Medicine at Dr RMLIMS, Lucknow. Consequent to acquisition of image data the reconstruction was undertaken on xeleris workstation with ECT toolbox. Various filters as described were used both in FBP and OSEM reconstruction techniques by selecting critical frequencies.

Results & Discussions: The value of EF was almost same in case of all filters when ROI was unchanged while processing but other parameters such as Summed Rest Score (SRS), Summed Stress Score (SSS) and Summed Difference Score (SDS=SSS-SRS) gave variable score on effect of change of filters and reconstruction types respectively.

Conclusion: The overall scrutiny of results and the image quality reveals that the Butterworth filter can be used to provide an optimal compromise between signal to noise ratio and clinically acceptable image quality in myocardial perfusion studies. The present study also suggests that Butterworth filter provides adequate and acceptable qualitative and quantitative assessments in MPI TC-99m cardiac SPECT/CT system.

Abbreviations: MPI: Myocardial Perfusion Imaging; SRS: Summed Rest Score; SSS: Summed Stress Score; SDS: Summed Difference Score; MTF: Modulation Transfer Function; SNR: Signal-To-Noise Ratio; LEHR: Low Energy High Resolution; EF: Ejection Fraction; TPD: Total Perfusion Deficit; OSEM: Ordered Subset Expected Maximization; FBP: Filtered Back Projection

Introduction

The branch of nuclear medicine specifically deals with nuclear cardiology focusing therein on assessing the function and viability of myocardial tissues. There have been many FDA and EMA approved radiopharmaceuticals used worldwide for myocardial perfusion imaging and viability assessment in both SPECT and PET modalities. However a conventional nuclear medicine SPECT study results in image noise due to statistical error at various steps starting from radiopharmaceuticals administration till image processing and usually deteriorates image quality. To compensate for this loss, filters are developed to preserve image details and to produce diagnostic images of optimum image quality [1]. The CT component used in hybrid imaging modalities are used for two fundamental workflows, one to provide anatomical image for better interpretation along with SPECT/PET images and second one for attenuation correction. X-ray transmission source from CT forms multiple projections around the region of interest and reconstruct the images with the help of various reconstruction techniques such as filtered back projection and iterative reconstruction which in turn uses various filters in the spatial or frequency domain to generate images of clinically acceptable qualities [1,2].

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Filters are mathematical tools designed to perform a variety of image processing algorithms such as smoothing, edge enhancement, and restoring resolution [1]. The main aim of using filter is to reduce the statistical noise and improve image resolution by the use of various parameters such as cut-off frequency, order, etc. There are a wide variety of filters available in medical imaging and the choice of each filter depends on the user preference, type of study conducted, and a compromise between the extent of noise reduction, fine detail suppression, and contrast enhancement, as well as the spatial frequency pattern of the image data of interest [2]. Filters can be applied either in frequency domain or in spatial domain and the use of reconstruction techniques such as Filtered back projection and iterative reconstruction are used to reconstruct the data generated by SPECT images [3]. In this article we have tried to mention only those filters provided to us by vendor in our xeleris workstation for image processing of MPI images post-acquisition.

Filters and their Modifications

Ramp filter is basically used to reduce the star artifact which was generated by simple back projection. It is a high pass filter which restrict the low frequency noise and thus prevents blurring in image. Since blurring occurs in transaxial orientation, the ramp filter also acts in axial section [4].

Smoothing filters are those mathematical algorithms designed to reduce noise by preserving the low frequency signals and blocking the high frequency signals respectively. There are many smoothing filters commonly employed in SPECT image processing. Some of them are worth mentioning as:

1. *Butterworth Filter*. Butterworth filter is most frequently used filter in nuclear medicine. It is lowpass filter. It is characterized by two parameters: the critical frequency also refers to cut-off frequency at which the filter attenuates the amplitude by 0.707and the order /power. *The order determines how rapidly the attenuation of amplitudes occur with increasing frequency* [1,5]. Higher the order, sharper the fall and lowering the critical frequency while maintaining the order results in more smoothing of the image.
2. *Hanning (Hann) Filter*. The Hanning filter is also a lowpass filter which preserve low frequency structures, while eliminating high frequency noise [2].
3. Hamming Filter. It is also a low pass filter which produce a high degree of smoothing [1,2].
4. Gaussian filter. It is a 2D convolution filter which removes noise and details of an image and cause smoothing. These filters also increase SNR but also cause image distortion, provided the size of filter, which makes the quantitative analysis difficult [6].

Enhancement or Restoration filters are used to enhance the contrast of edges in an image or the signal by simultaneously reducing the noise without compromising resolution lost. The two types of resolution recovery filters that have been used in nuclear medicine image processing are Metz and Wiener.

Metz Filter [7,8].

1. Metz filter. It is a function of modulation transfer function (MTF), and it is based on the measured MTF of the gamma camera system. The MTF describes how the system handles or degrades the frequencies.
2. Wiener filter. The Wiener filter is based on the signal-to-noise ratio (SNR) of the specific image [2]. Wiener is the product of the inverse filter (which shows the resolution recovery) and the low pass filter (which shows the noise suppression). To apply the Wiener filter, we must know priori the MTF, the power spectrum of the object and noise. It must be noted that is, impossible to know exactly the MTF or the SNR in any image and thus, the mathematical models used to optimize both Metz and Wiener filters are uncertain in nature [8].

The use of various filters may be selected depending on the type of examination. The filter choice depends on [9,10]:

(i) The energy of the isotope, the number of counts and the activity administration.

(ii) The statistical noise and the background noise level.

(iii) The type of the organ being imaged

(iv) The kind of information we want to obtain from the images.

(v) The collimator that is used.

The choice of the filter must ensure the best compromise between the noise reduction and the resolution in the image.

Materials and Methodology

The present study was conducted in the department of Nuclear Medicine, Dr RMLIMS, Lucknow on the cases referred for Myocardial perfusion imaging (MPI) scan using Tc-99m sestamibi radiopharmaceutical. It is a retrospective study conducted on 30 patients in a SPECT system of NEW DISCOVERY NM/CT 670 SERIES.

Procedure Protocol

- Radiopharmaceutical used: 99mTc- sestamibi (10-30)mCi
- Patient preparation: Nill per oral for 4-6 hours
- SPECT imaging protocol: Two-day protocol

Day 1-Rest: 8-10 mCi (296-370 MBq); imaging at 30 to 90 minutes

Day 2-Stress: 24-30 mCi (888-1110 MBq); imaging at 15 to 30 minutes

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- SPECT acquisition parameters

Patient position: supine, left arm raised

(180-degree arc)

Rotation: counterclockwise

Matrix: 128 × 128-word mode

Frame rate-25 sec per stop

Image/arc: 64 views

- SPECT reconstruction parameters

Convolution filter: Butterworth, Attenuation correction to review images with and without correction.

Oblique angle reformatting: Short-axis, vertical long-axis, and horizontal long-axis gated SPECT Electrocardiogram synchronized data collection: R wave trigger, 16 frames/cardiac cycle

Acquisition protocol

- Collimator: Low Energy High Resolution (LEHR)
- Window: 20% centered at 140 keV
- Dual heads of gamma camera in L-mode
- Stress and rest images are obtained in identical projection

Data reconstruction was undertaken on Xeleris workstation with ECT toolbox. Various filters as described were used both in FBP and OSEM reconstruction techniques by selecting critical frequencies and order. The various filters were explored in SPECT reconstruction options for both FBP and iterative reconstruction and without changing the ROI on the myocardium. We tried to use all the options available to us as provided by the vendor and the values of each parameter were evaluated in reference to image quality as reported by 3 independent nuclear medicine physicians (Table 1).

Table 1: Represents the various parameters used for different filters with defined range of values for optimum image quality. The calculated Ejection fraction (EF) and other parameters are shown in the table. As shown by the table there is minimal variation in EF of MPI study performed without changing the ROI but other parameters such as Summed Rest Score (SRS), Summed Stress Score (SSS) and Summed Difference Score (SDS) gives variable results respectively as generated by polar maps in the Xeleris workstation. Here, we have shown the following results for 8 patients.

SL NO	RECONSTRUCTION TYPE	FILTERS	PARAMETERS	EF	SRS	SSS	SDS	DIFFERENCE
SUBJECT 1 (REST)	OSEM/MLEM (ITERATIVE RECONSTRUCTION)	BUTTERWORTH	CF:0.45,P: 10.00	57%	8	-		
		HANN	CF: 1.14	57%	8	-		
		GAUSS	FWHM X,Y :1.13 FWHM Z: 1.55	59%	9	-		
	FBP	HANN	CF: 1.14	59%	9	-		
		BUTTERWORTH	CF: 0.45, P:10.00	56%	9	-		
		METZ	POINTSPREAD =2.5,ORDER =1.81	56%	14	-		
		WIENER	POINTSPREAD =4,Pn/PF =1.81	58%	8	-		
		HAMMING	CF:0.62, ALPHA :0.47	57%	14	-		
SUBJECT 2 (REST+STRESS)	OSEM/MLEM (ITERATIVE RECONSTRUCTION)	BUTTERWORTH	CF:0.45,P:10.00	R-78%,S-76%	0	3	3	
		HANN	CF:1.14	R-79%, S-76%	0	3	3	
		GAUSS	FWHM X,Y=1.13, FWHM Z=1.55	R-79%, S-76%	0	1	1	
	FBP	HANN	CF: 1.14	R-77%, S-76%	2	1	1	
		BUTTERWORTH	CF-0.45, P=10	R-73%, S-76%	0	0	0	
		METZ	POINTSPREAD=2.5,ORDER=1.81	R-77%, S-76%	2	0	2	
		WEINER	PS=4, Pn/PF= 0.19	R-76%, S-74%	7	0	7	
		HAMMING	CF=0.62, ALPHA=0.47	R-77%, S-75%	2	0	2	

SUBJECT 3 (REST+STRESS)	OSEM/MLEM (ITERATIVE RECONSTRUC-TION)	BUTTER-WORTH	CF:0.45,P:10.00	R-79%, S-75%	12	4	-8	
		HANN	CF:1.14	R-79%, S-75%	8	4	-4	
		GAUSS	FWHM X,Y=1.13, FWHM Z=1.55	R-81%, S-75%	12	6	-6	
	FBP	HANN	CF: 1.14	R-82%, S-75%	13	5	-8	
		BUTTER-WORTH	CF-0.45, P=10	R-80%, S-76%	13	6	-7	
		METZ	POINTSPREAD=2.5,ORDER=1.81	R-80%, S-75%	12	7	-5	
		WEINER	PS=3.74, Pn/PF= 0.19	R-79%, S-72%	12	6	-6	
		HAMMING	CF=0.97, ALPHA=0.44	R-80%, S-73%	11	5	-5	
SUBJECT 4 (REST+STRESS)	OSEM/MLEM (ITERATIVE RECONSTRUC-TION)	BUTTER-WORTH	CF:0.45,P:10.00	R-55%, S-54%	4	8	4	
		HANN	CF:1.14	R-55%, S-58%	4	9	5	
		GAUSS	FWHM X,Y=1.13, FWHM Z=1.55	R-56%, S-54%	8	9	1	
	FBP	HANN	CF: 1.14	R-54%, S-56%	4	8	4	
		BUTTER-WORTH	CF-0.45, P=10	R-53%, S-56%	2	5	3	
		METZ	POINTSPREAD=2.5,ORDER=1.81	R-54%, S-56%	7	4	-3	
		WEINER	PS=3.25, Pn/PF= 0.19	R-53%, S-55%	5	8	3	
		HAMMING	CF=1.23, ALPHA=0.50	R-51%, S-55%	2	6	4	
SUBJECT 5 (REST+STRESS)	OSEM/MLEM (ITERATIVE RECONSTRUC-TION)	BUTTER-WORTH	CF:0.45,P:10.00	R-65%, S-67%	6	9	3	
		HANN	CF:1.14	R-67%, S-66%	7	8	1	
		GAUSS	FWHM X,Y=1.13, FWHM Z=1.55	R-65%, S-66%	7	3	-4	
	FBP	HANN	CF: 1.14	R-65%, S-67%	8	7	-1	
		BUTTER-WORTH	CF-0.45, P=10	R-65%, S-65%	7	9	2	
		METZ	POINTSPREAD=2.5,ORDER=1.81	R-65%, S-67%	5	3	-2	
		WEINER	PS=3.10, Pn/PF= 0.10	R-65%, S-67%	7	8	1	
		HAMMING	CF=1.09, ALPHA=0.47	R-66%, S-65%	6	7	1	
SUBJECT 6 (REST+STRESS)	OSEM/MLEM (ITERATIVE RECONSTRUC-TION)	BUTTER-WORTH	CF: 0.45, P: 10	R-72%,S-56%	12	20	8	
		HANN	CF: 1.14	R-72%,S-55%	15	20	5	
		GAUSS	FWHM X,Y :1.13,FWHM Z :1.55	R-72%,S-55%	15	21	6	
	FBP	HANN	CF:1.14	R-72%,S-55%	16	24	8	

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		BUTTER-WORTH	CF:0.45, P:10	R-72%,S-55%	17	24	7	
		METZ	POINTSPREAD =2.5,ORDER =1.81	R-73%,S-56%	18	22	4	
		WEINER	POINTSPREAD =3.55,Pn/PF =0.16	R-73%,S-56%	14	23	9	
		HAMMING	CF =0.88, ALPHA =0.47	R-71%,S-55%	16	21	5	
SUBJECT 7 (REST+STRESS)	OSEM/MLEM (ITERATIVE RECONSTRUC-TION)	BUTTER-WORTH	CF:0.45,P:10	R-85%,S-77%	0	2	2	
		HANN	CF:1.14	R-84%,S-77%	0	2	2	
		GAUSS	FWHM X,Y :1.13,FWHM Z :1.55	R-85%,S-77%	0	0	0	
	FBP	HANN	CF:1.14	R-85%,S-78%	0	2	2	
		BUTTER-WORTH	CF:0.45,P:10	R-85%,S-78%	0	0	0	
		METZ	POINTSPREAD =2.5,ORDER=2.53	R-82%,S-77%	0	1	1	
		WEINER	POINTSPREAD =3.4,Pn/PF=0.16	R-84%,S-76%	0	3	3	
		HAMMING	CF=0.92, ALPHA=0.47	R-83%,S-78%	0	0	0	
SUBJECT 8 (REST)	OSEM/MLEM (ITERATIVE RECONSTRUC-TION)	BUTTER-WOTH	CF:0.45,P:10	R -37%	17	-		
		HANN	CF:1.14	R-38%	16	-		
		GAUSS	FWHM X,Y:1.13,FWHM Z:1.55	R-39%	15	-		
	FBP	HANN	CF:1.14	R-39%	15	-		
		BUTTER-WORTH	CF:0.45,P:10	R-38%	17	-		
		METZ	POINTSPREAD =2.5,ORDER=1.81	R-39%	15	-		
		WEINER	POINTSPREAD =2.95,Pn/PF=0.19	R-39%	14	-		
		HAMMING	CF :0.80, ALPHA :0.49	R-40%	17		-	

Vendor specific software generating semiquantitative evaluation of left ventricular perfusion represented by 17 segments polar map provides global and regional scoring of myocardial perfusion with a 5-point scoring system: [11]

0-Normal

1-Equivocal

2-Moderate reduction

3-Severe reduction

4-Absent

(Figure 1) The global scoring of myocardial perfusion uses measures such as: the Summed Stress Score (SSS), the Summed Rest Score (SRS), and the Summed Difference Score (SDS) where SDS = SSS-SRS [11,12] (Tables 2 & 3).

Table 2.

SCORE	PERFUSION % IN COMPARISON TO 100% RADIOTRACER ACCUMULATION
1 or 2	60%
3	40%-60%
4	< 40%

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Table 3.

SSS	SS%	SDS	TPD (%)	Result
<4	<5	< 2	<5	Normal or minimally abnormal result
4-8	5-9	2-4	5-9	Mildly abnormal result
9-13	10-14	5-6	10-14	Moderately abnormal result
> 13	> 14	> 6	> 14	Significantly abnormal result

Note: SSS – summed stress score, SS% – summed stress percentage, SDS – summed difference score, TPD – total perfusion deficit (percentage)

Results & Discussions

The value of EF was almost same in case of all filters when ROI was unchanged while processing but other parameters such as Summed Rest Score (SRS), Summed Stress Score (SSS) and Summed Difference Score (SDS=SSS-SRS) gave variable score on effect of change of filters and reconstruction types respectively. A variety of filters including Hann, Butterworth, Gauss, Metz, Wiener and Hamming both in FBP (Filtered Back Projection) and iterative reconstruction (Ordered Subset Expected Maximization) mode of image reconstruction are used with their respective parameters such as cut-off frequency, order, FWHM(X,Y), FWHM Z, POINTSPREAD, order, alpha, etc. It is observed that the value which provide optimal and variable image quality depends on their respective different values as depicted in the tabular form bellow: (Table 4). The image quality was reported by three independent Nuclear Medicine physician in the XELERIS workstation after acquisition of cardiac scan following the standard operating protocol of our department (Figures 2,3 & 4).

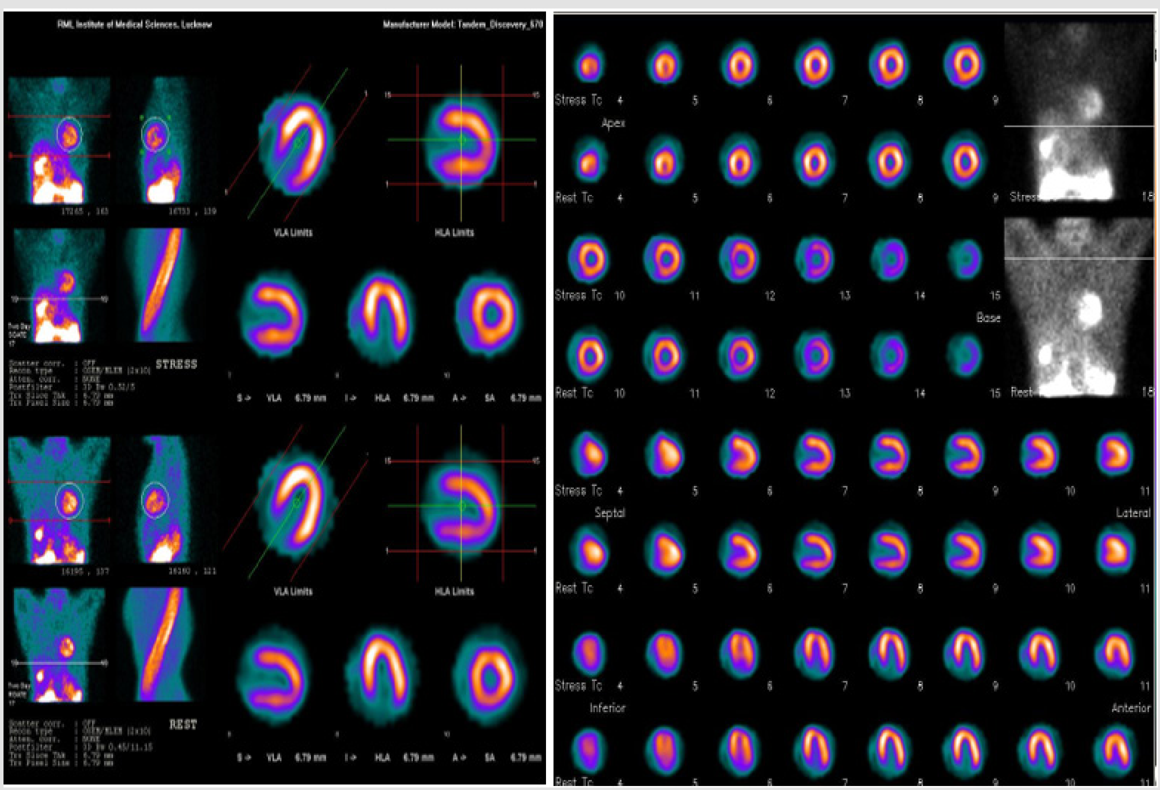

Figure 2: Represents the placement of ROI on the region of interest and generation of images in short axis, vertical long axis and horizontal long axis in case of both rest and stress MPI scan.

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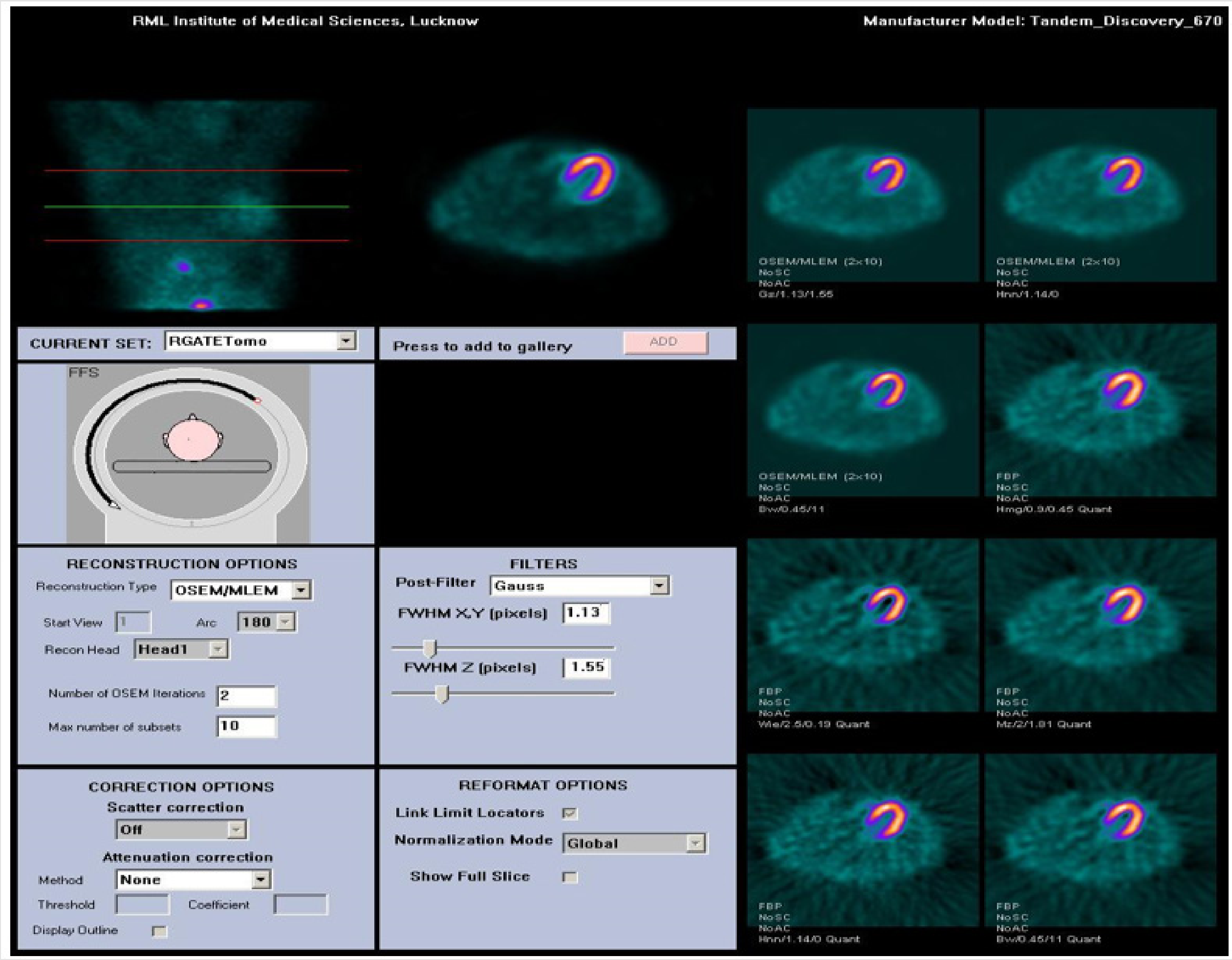

Figure 3: Represents the use of various filters in both reconstruction techniques of FBP and OSEM (iterative reconstruction) and their respective generated images on the left side of the shown images in a rest MPI data. Image generated in the department of Nuclear Medicine, Dr RMLIMS, Lucknow.

Table 4.

TYPES OF FILTERS	PARAMETERS	PARAMETERS	OBSERVED IMAGE QUALITY
BUTTERWORTH	CUT-OFF FREQUENCY :0.45	ORDER :10	OPTIMAL, GOOD SIZE ACCURACY WITH APPROPRIATE EJECTION FRACTION
HANN	CUT-OFF FREQUENCY: 1.14	-	OPTIMAL
GAUSSIAN FILTER	FWHM(X,Y):1.13, FWHM Z :1.55	-	OPTIMAL
WIENER	POINTSPREAD :2.5	Pn/PF: 0.10-0.19	MINIMAL TO MODERATE
HAMMING	CUT-OFF FREQUENCY :0.62-1.09	ALPA(α): 0.44 – 0.50	MINIMAL TO MODERATE
METZ	-	ORDER :10,POINT SPREAD (2-5)	OPTIMAL

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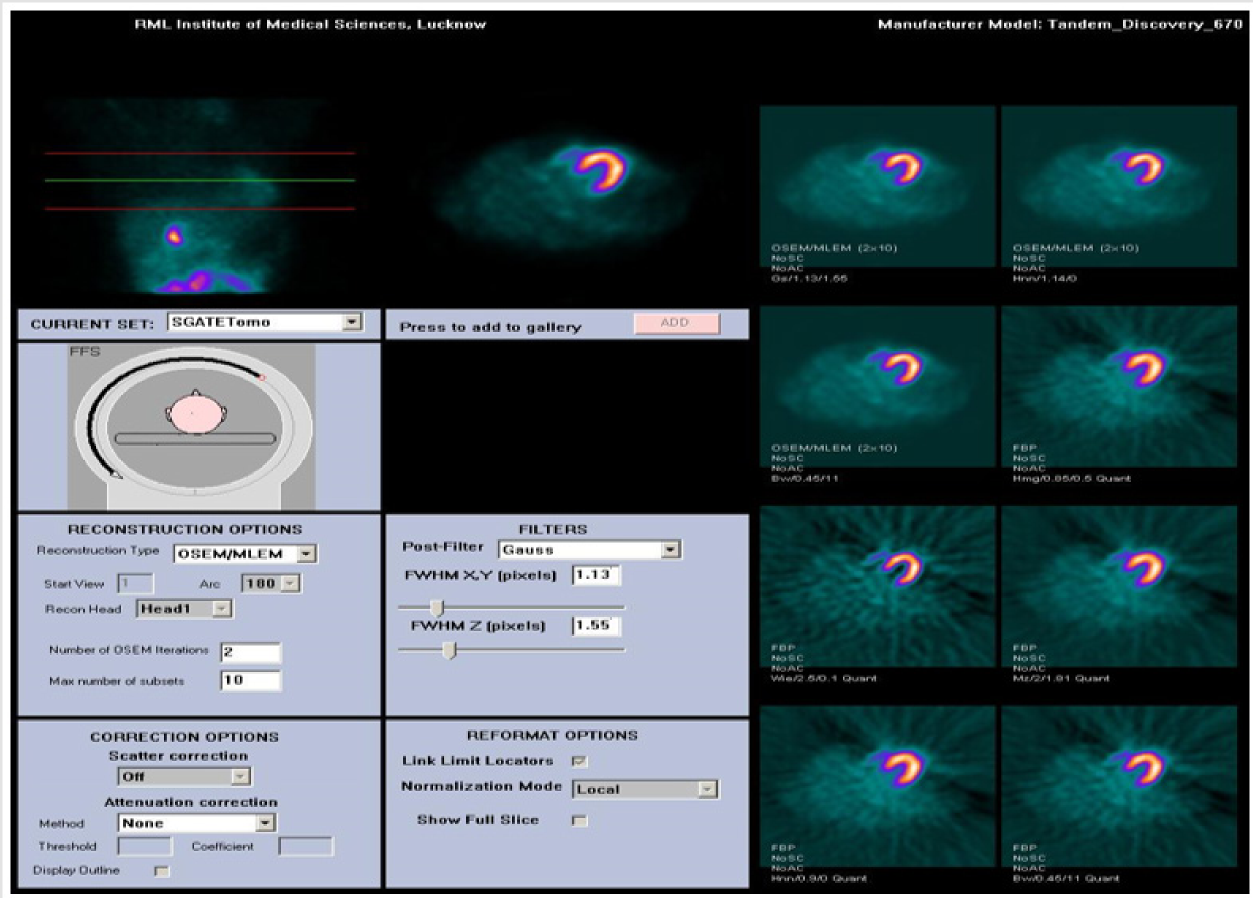

Figure 4: Represents the use of various filters in both reconstruction techniques of FBP and OSEM (iterative reconstruction) and their respective generated images on the left side of the shown images in a stress MPI data. Image generated in the department of Nuclear Medicine, Dr RMLIMS, Lucknow.

Conclusion

The overall scrutiny of results and the image quality reveals that the Butterworth filter can be used to provide an optimal compromise between signal to noise ratio and enable clinically acceptable image quality in myocardial perfusion studies. The present study also suggests that Butterworth filter provides adequate and acceptable qualitative and quantitative assessments in MPI TC-99m cardiac SPECT/CT system. We also found that the EF remains unchanged with fixed ROI position during processing whether other image parameters like (SRS, SRS, SDS) changes with change in different filters in both FBP and OSEM/Iterative reconstruction techniques. In a given set up it would always be advisable to use various filters or their combination to obtain an optimal image giving desired diagnostic information.

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