Optimization of Ordered Subset Expectation Maximization Parameters for Image Reconstruction in Tc-99m Methoxyisobutylisonitrile Myocardial Perfusion SPECT and Comparison with Corresponding Filtered Back Projection-Reconstructed Images

Abstract

Purpose of the Study: To establish the most appropriate ordered subset expectation maximization (OSEM) parameters for image reconstruction in Tc-99m methoxyisobutylisonitrile (MIBI) myocardial perfusion SPECT (MPS) and comparison with corresponding filtered back projection (FBP)-reconstructed images. Methods: A total of 99 stress–rest MPS studies (47 normal and 52 abnormal) were retrospectively analyzed using 16 different combinations of iterations and subsets. Images were reconstructed both with and without postreconstruction Butterworth filter (cutoff frequency and order for stress: 0.4 and 10 and for rest: 0.52 and 5, respectively) for each combination. A total of 3168 images were evaluated qualitatively by two nuclear medicine physicians on a scoring scale of 1–4. Best visual quality image iteration–subset combination was determined for each patient both with and without Butterworth filter and was further compared with FBP-reconstructed image. The interobserver agreement was obtained using kappa statistics. Results: The best quality images were obtained using a combination of four iterations and six subsets for both with and without Butterworth filter. The value of kappa for interobserver agreement for OSEM images with Butterworth filter was 0.570 and for OSEM images without Butterworth filter was 0.857. On comparison, FBP images were better than OSEM-reconstructed images without Butterworth filter (P < 0.0001 calculated using Fisher’s exact test) with substantial agreement (kappa = 0.628). However, OSEM-reconstructed images with Butterworth filter were better than FBP images and showed moderate agreement (kappa = 0.486). Conclusion: The most appropriate OSEM reconstruction parameter in Tc-99m MIBI MPS is 4-iteration and 6-subset combination. FBP-reconstructed images were better than the images reconstructed with OSEM without postreconstruction Butterworth filter. However, OSEM-reconstructed image with Butterworth filter was better than FBP images.

Keywords: Filtered back projection, image reconstruction, myocardial perfusion SPECT, ordered subset expectation maximization

Introduction

Filtered back projection (FBP) and iterative reconstruction (IR) are the two methods used for image reconstruction in myocardial perfusion scintigraphy.[1] IR is mainly of two types – maximum likelihood expectation maximization reconstruction technique and ordered subset expectation maximization (OSEM).[1,2] Myocardial perfusion SPECT (MPS) images reconstructed with OSEM IR algorithm have a superior quality than those processed with FBP.[1] Perfusion defects, anatomic variants, and the right ventricular myocardium are better visualized with OSEM. Likewise, image contrast is improved, thereby better defining the left ventricular endocardial borders.[1] Despite these advantages, the iterative methods were not considered as a convenient option, due to the great computational effort required during image reconstruction, as they require the repetition of projection and back projection mathematical operations.[3] FBP being a faster and easily implemented technique has been the most commonly used method of reconstruction and is widely applied clinically.[1,4,6]

With modern technology and advanced processors, the IR methods have become clinically viable, proving to be a powerful tool for image reconstruction with high-quality images. The most commonly used parameters for IR reconstruction are the number of iterations and subsets, which determine the trade-off between image quality and computational time.

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Several studies in the recent past have focused on the optimization of OSEM reconstruction parameters in MPS.[3,7–11] However, most of these studies are based on phantom for optimization of OSEM parameters. Furthermore, comparison of OSEM reconstruction and FBP reconstruction which is a routinely used method has been performed mostly on phantom-based studies.[8,9] In a study by Bai et al., OSEM and FBP images of real-time patient studies have been compared, but a fixed OSEM parameter (phantom derived) was used.[12] Hence, there is no study wherein optimization of OSEM parameters has been done on patient’s images and the same compared with FBP images. In addition, there are no studies based on the Indian population, and so, there exist no optimal parameters of OSEM that can be used in our patient studies. Therefore, this study was planned to optimize OSEM reconstruction parameters in MPS and compare the same with FBP-reconstructed images.

In this study, we aimed to determine the most appropriate parameters for IR using OSEM for reconstruction of MPS images and compare them with the commonly and routinely used FBP-reconstructed images.

**Methods**

The study was approved by the institutional ethics committee. This was a retrospective study. A total of 99 stress–rest MPS studies of 47 normal and 52 abnormal patients (all aged >18 years) were included, each of which were processed using 16 different combinations of iterations and subsets and analyzed. The Tc-99m methoxyisobutylisonitrile (MIBI) MPS images that had already been acquired were used for analysis and comparison. Studies with only stress or only rest acquisitions or with Tc-99m MIBI MPS acquisition done in 2-day stress/rest protocol, patient’s images with motion artifacts, or patient’s images with overlapping anatomical structures in relation to heart were not included in the study.

All the studies that were acquired in a 1-day stress–rest protocol were included. The standard dosage of Tc-99m MIBI for stress study was 296–370 MBq or 8–10 mCi (5.55 MBq/kg or 0.15 mCi/Kg) and for rest study was 925–1110 MBq or 25–30 mCi (16.7 MBq/kg or 0.45 mCi/Kg) injected intravenously. All the patients’ images included in the study were acquired on GE Infinia Hawkeye dual-head Gamma Camera mounted with low-energy all purpose collimators with parallel hole. The imaging was performed with electrocardiographic synchronization in auto tracking mode with 8 frames per cardiac cycle. The SPECT acquisition was done in step-and-shoot mode with noncircular body contoured orbit with a total of 60 projections (30 projections for each detector), and images were acquired over 180° from right anterior oblique to left posterior oblique view in L-mode in the counterclockwise rotation. Time for each projection was 20 s leading to total scan duration of approximately 14 min. A zoom factor of 1.3 was used, and the images were acquired in 64 × 64 matrix with the photopoint centered at 140 KeV for Tc-99m with 20% window. No attenuation correction or scatter correction algorithms were used.

**Processing of the images**

Motion correction, if required, was done by the use of motion correction software either by automatic or by manual correction. The acquired stress and rest images were reconstructed using FBP as per the standard parameters routinely used in our department (Butterworth filter with critical frequency of 0.4 and order 10 for stress images and critical frequency of 0.52 and order 5 for rest images) which is vendor provided (Xeleris, GE Healthcare). Reconstructed images were displayed as coronal (vertical long-axis), sagittal (horizontal long-axis), and transaxial (short-axis) slices.

Images were also reconstructed by IR technique using OSEM. Different combinations of number of iterations and number of subsets were assessed. Arrangements of 2, 4, 6, and 8 iterations with 2, 6, 10, and 16 subsets giving 16 different combinations (2-2, 2-6, 2-10, 2-16, 4-2, 4-6, 4-10, 4-16, 6-2, 6-6, 6-10, 6-16, 8-2, 8-6, 8-10, and 8-16) were analyzed to determine the combination which provides images of best diagnostic quality. OSEM reconstruction was done both with and without postreconstruction Butterworth filter for each iteration–subset combination. Reconstructed images were displayed as coronal (vertical long-axis), sagittal (horizontal long-axis), and transaxial (short-axis) slices.

All images reconstructed with different combinations of OSEM parameters were evaluated for image quality in terms of target to background ratio, overall image quality, as well as changes in images, leading to loss of information. Analysis was done by two nuclear medicine (NM) physicians independently. Images were graded on a scale of 1–4 with: 1 = extremely noisy/smooth image (not readable and cannot be used for clinical interpretation); 2 = very noisy/smooth image (readable but cannot be used for clinical interpretation); 3 = noisy/smooth image (can be used for clinical interpretation but loss of information possible); and 4 = optimum noise/smoothening (image appropriate for clinical interpretation with no loss of information expected). All the OSEM-reconstructed images with and without postreconstruction Butterworth filter for each iteration–subset combination were graded.

For comparison, the best OSEM images (both OSEM with filter and OSEM without filter) selected were compared with the corresponding FBP images for each patient study and analyzed independently by two NM physicians using three-point grading as: 1 = OSEM images poorer than FBP images (overall poor image quality in OSEM or loss of
information in OSEM-reconstructed images; 2 = OSEM images similar to FBP images (same image quality with no loss or addition of information); 3 = OSEM images better than FBP images (overall better image quality in OSEM or addition of information in OSEM-reconstructed images).

Results

For each patient, a total of 32 images were analyzed including 16 images with Butterworth filter and another 16 images without reconstruction with Butterworth filter being obtained using 16 combinations of iterations and subsets. For 99 patients’ studies included in the study, a total of 3168 images were reconstructed with OSEM parameters which were analyzed and graded.

When OSEM reconstruction was done without postreconstruction Butterworth filter, the best images (Grade 4) selected were most frequently the images reconstructed using iteration−subset combination of 4–6 by both the NM physicians, and there was almost perfect agreement between the two observers (kappa = 0.857). The summary of frequencies of the iteration−subset combination with best image quality grading using OSEM without postreconstruction Butterworth filter for both the observers is shown in Table 1 and Figure 1.

When OSEM reconstruction was done using postreconstruction Butterworth filter, the best images (Grade 4) selected were again the images reconstructed using iteration−subset combination of 4–6 by both the NM physicians, and there was moderate agreement between the two observers (kappa = 0.570) as summarized in Table 2 and Figure 2.

Comparison of ordered subset expectation maximization-reconstructed images with the images reconstructed with filtered back projection using standard parameters

When the best images judged on OSEM reconstruction without postreconstruction Butterworth filter were compared with the corresponding FBP images, both the observers scored the FBP images better than the OSEM-reconstructed images ($P < 0.0001$ calculated using Fisher’s exact test), and a substantial agreement (kappa = 0.628) was found between the two observers [Table 3 and Figure 3].

However, when the best images judged on OSEM reconstruction with postreconstruction Butterworth filter were compared with the corresponding FBP images, both the observers scored the OSEM images better

| Iteration | Subset | Frequency |
|-----------|--------|-----------|
| 2         | 2      | 0         |
| 2         | 6      | 2         |
| 2         | 10     | 15        |
| 2         | 16     | 3         |
| 4         | 2      | 0         |
| 4         | 6      | 68        |
| 4         | 10     | 0         |
| 4         | 16     | 0         |
| 6         | 2      | 1         |
| 6         | 6      | 2         |
| 6         | 10     | 0         |
| 6         | 16     | 0         |
| 8         | 2      | 8         |
| 8         | 6      | 0         |
| 8         | 10     | 0         |
| 8         | 16     | 0         |

Table 1: Frequencies of the iteration-subset combination with best image quality grading in images of 99 patients studies using ordered subset expectation maximization without postreconstruction Butterworth filter

| Iteration | Subset | Frequency |
|-----------|--------|-----------|
| 2         | 2      | 0         |
| 2         | 6      | 0         |
| 2         | 10     | 4         |
| 2         | 16     | 5         |
| 4         | 2      | 0         |
| 4         | 6      | 83        |
| 4         | 10     | 4         |
| 4         | 16     | 0         |
| 6         | 2      | 0         |
| 6         | 6      | 1         |
| 6         | 10     | 0         |
| 6         | 16     | 0         |
| 8         | 2      | 1         |
| 8         | 6      | 1         |
| 8         | 10     | 0         |
| 8         | 16     | 0         |

Table 2: Frequencies of the iteration-subset combination with best image quality grading in images of 99 patients studies using ordered subset expectation maximization with postreconstruction Butterworth filter

Figure 1: Graph showing the frequencies of the iteration–subset combination with best image quality grading in images of 99 patients studies using ordered subset expectation maximization without postreconstruction Butterworth filter
than the FBP-reconstructed images, and a moderate agreement (kappa = 0.486) was found in the results of both the NM physicians [Table 4 and Figure 4].

The results from both the NM physicians were concordant and have shown that when OSEM reconstruction was done with postreconstruction Butterworth filter, a combination of four iterations and six subset reconstruction parameters gave the best quality images.

Images of different reconstruction settings for comparison are depicted in Figure 5.

### Discussion

The more widely available and increasingly fast IR method OSEM is being used progressively more often as a substitute for FBP because OSEM presents superior image quality and a higher signal-to-noise ratio. Both reconstruction methods (FBP and OSEM) are affected by their own reconstruction parameters, such as the cutoff frequency and order in FBP and the number of iterations and subsets in OSEM. Different institutes use different parameters for the reconstruction in MPS based upon the normal database of their population. It is mentioned in the IAEA guidelines that if FBP is used, the type of filter, cutoff frequency, and order factors might follow the recommendations of vendors if standard activity amounts of tracers and imaging techniques are applied. The vendor (Xeleris, GE Healthcare) provided parameters in our institute for image reconstruction using FBP with Butterworth filter use a cutoff frequency of 0.4, order of 10 for stress images (296–370 MBq or 8–10 mCi) and a cutoff frequency of 0.52, order of 5 for rest images (925–1110 MBq or 25–30 mCi). Parameters for the reconstruction with FBP have also been mentioned in the guidelines. The IAEA recommends the reconstruction parameters for Butterworth filter with cutoff frequency of 0.3–0.46, order of 6 (for 296–444 MBq or 8–12 mCi) for stress images and cutoff frequency of 0.4–0.56, order of 6 (for 666–1110 MBq or 18–30 mCi) for rest images. The EANM guidelines recommend a cutoff frequency of 0.3–0.4 and order of 6 for stress images and cutoff frequency of 0.4–0.5 and order of 6 for rest images. However, OSEM parameters have not been clearly defined in any of the guidelines.

Therefore, in this study, we have tried to optimize OSEM reconstruction parameters in MPS and compared the best image from OSEM-reconstructed images with FBP-reconstructed images of the same patient study.
Several studies in the past have focused on optimization of OSEM reconstruction parameters in MPS, but most of these are phantom-based studies.[7-11] A study by Duarte et al. based on a beating heart phantom recommended the use of combinations 2 iterations × 10 subsets or 2 iterations × 12 subsets parameters for the reconstruction with OSEM in MPS.[13] Another hot-spot phantom-based study by Yanagisawa and Maru on 36 SPECT images stated that the values of 2 and 15 were optimum for iteration and the number of subset, respectively.[8] However, these studies were phantom based; no real patient images were used in these studies to standardize OSEM reconstruction parameters in MPS.

In a study on real-time patients MPS, de Barros et al. identified the most appropriate OSEM parameters with the arrangement of 4 iterations with 4 subsets in case of patients with normal body mass index (BMI) and combination of 6 iterations and 4 subsets in the overweight and higher obesity classes.[9] In their study, they determined the OSEM reconstruction parameters in patients, but they did not optimize and compare the best iteration–subset image from OSEM with FBP.

There is only one study in the literature in which comparison of OSEM-reconstructed images was done with FBP-reconstructed images in real patient studies.

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**Table 4: Comparison of the iteration-subset combination with best image quality on ordered subset expectation maximization with postreconstruction filter and corresponding filtered back projection images for both the observers**

| Iteration | Subset | Nuclear medicine physician 1 | Nuclear medicine physician 2 |
|-----------|--------|------------------------------|------------------------------|
|           | Frequency | OSEM better | FBP better | Equal | Frequency | OSEM better | FBP better | Equal |
| 2         | 2       | 0             | 0             | 0             | 0             | 0             | 0             | 0             |
| 2         | 6       | 0             | 0             | 0             | 0             | 0             | 0             | 0             |
| 2         | 10      | 4             | 4             | 0             | 0             | 5             | 4             | 1             |
| 2         | 16      | 5             | 3             | 1             | 1             | 6             | 4             | 1             |
| 4         | 2       | 0             | 0             | 0             | 0             | 0             | 0             | 0             |
| 4         | 6       | 83            | 74            | 0             | 9             | 78            | 67            | 0             |
| 4         | 10      | 4             | 3             | 1             | 0             | 5             | 5             | 0             |
| 4         | 16      | 0             | 0             | 0             | 0             | 0             | 0             | 0             |
| 6         | 2       | 0             | 0             | 0             | 0             | 0             | 0             | 0             |
| 6         | 6       | 1             | 1             | 0             | 0             | 4             | 4             | 0             |
| 6         | 10      | 0             | 0             | 0             | 0             | 0             | 0             | 0             |
| 6         | 16      | 0             | 0             | 0             | 0             | 0             | 0             | 0             |
| 8         | 2       | 1             | 1             | 0             | 0             | 1             | 1             | 0             |
| 8         | 6       | 1             | 1             | 0             | 0             | 0             | 0             | 0             |
| 8         | 10      | 0             | 0             | 0             | 0             | 0             | 0             | 0             |
| 8         | 16      | 0             | 0             | 0             | 0             | 0             | 0             | 0             |

OSEM: Ordered subset expectation maximization, FBP: Filtered back projection
Bai et al. compared FBP (Butterworth filter with cutoff frequency - 0.15, order - 8) and OSEM (Butterworth filter with cutoff frequency - 0.17, order - 8) in 102 patients and OSEM was performed with 3-iteration and 9-subset combination.\textsuperscript{[12]} They found no significant difference between sensitivity and specificity of FBP and OSEM reconstruction in their study. However, they did not optimize the OSEM reconstruction parameters using different combinations of iterations and subsets and used only a specific combination of 3 iterations with 9 subsets in their study, according to most studies based on phantom experiments.

In our study, we have optimized OSEM reconstruction parameters using 32 different combinations of iterations and subsets (OSEM with and without postreconstruction Butterworth filter) and also compared the best image from OSEM-reconstructed images with FBP-reconstructed image of the same patient study.

The iteration–subset combination for the best images in each study was determined to ascertain the most appropriate combination for image reconstruction using OSEM. When analysis of the images of 99 patients’ studies was done using OSEM reconstruction without postreconstruction Butterworth filter, the iteration–subset combination of 4–6 was most frequently selected by both the NM physicians. When analyzing OSEM reconstruction with postreconstruction Butterworth filter, it was again 4-iteration and 6-subset combination that provided the best quality images.

When the best images obtained using OSEM with postreconstruction Butterworth filter were compared with the corresponding FBP-reconstructed images, OSEM images were judged to be superior to FBP images by both the observers. The results of both the NM physicians were compared using kappa statistics, and a moderate agreement (kappa = 0.486) was found. This agreement is less than the agreement observed when comparing OSEM images without postreconstruction filter with FBP images. The OSEM images without filter are noisy; hence, when compared to FBP images, an appreciable difference is noted, leading to higher agreement between observers.

To our knowledge, this is the first study in which optimization of OSEM reconstruction parameters, with and
without filter, has been done on real-time patient studies and the same compared to the corresponding FBP images. Our results are slightly different from the values mentioned in previous studies, in which 2 iterations with 10 or 12 subsets have been recommended in one study and 2 iterations and 15 subsets are mentioned in another study. However, unlike our study, both these studies were phantom based. Also, our results are in accordance with the international guidelines that a minimum of 2 iterations and a maximum of 8 subsets should be used for OSEM reconstruction when the number of projections is 32–64. In our study, we have not used attenuation correction algorithm, and no analysis has been done with regard to attenuation-corrected images. This is because we wanted to analyze native images without introducing additional variables such as attenuation correction or scatter correction, which may have its own confounding effect on the images and affect the homogeneity of the patient studies. Another limitation of our study is that we did not take into account the effect of BMI on quality of images because of retrospective nature of our study. Further, we had included MPS of both genders and MPS studies with normal perfusion and with perfusion abnormalities in our study. However, separate analysis was not performed to account for gender difference and the effect of perfusion abnormalities. In addition, in routine practice, the most appropriate reconstruction parameters would be applied universally for all the studies.

Conclusion

The most appropriate OSEM parameter for image reconstruction in Tc-99m-MIBI MPS was the 4-iteration 6-subset combination, for both with and without postreconstruction Butterworth filter. On comparison, the FBP images were better than OSEM-reconstructed images without postreconstruction filter. However, OSEM-reconstructed images with postreconstruction filter were better than FBP-reconstructed images. Therefore, the study shows that OSEM reconstruction performed with 4-iteration and 6-subset combination with postreconstruction Butterworth filter is most appropriate for processing MPS studies.

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Conflicts of interest

There are no conflicts of interest.

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