

EM-IntraSPECT Algorithm With Ordered Subsets (OSEMIS) for Non-Uniform Attenuation Correction in Cardiac Imaging

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Keywords: iterative reconstruction, ordered subsets, attenuation compensation, myocardial SPECT

ABSTRACT

Performance of the EM-IntraSPECT (EMIS) algorithm with ordered subsets (OSEMIS) for non-uniform attenuation correction in the chest was assessed. EMIS is a maximum-likelihood expectation maximization (MLEM) algorithm for simultaneously estimating SPECT emission and attenuation parameters from emission data alone. EMIS uses the activity within the patient as transmission tomography sources, with which attenuation coefficients can be estimated. However, the reconstruction time is long. The new algorithm, OSEMIS, is a modified EMIS algorithm based on ordered subsets. Emission Tc-99m SPECT data were acquired over 360° in non-circular orbit from a physical chest phantom using clinical protocol. Both a normal and a defect heart were considered. OSEMIS was evaluated in comparison to EMIS and a conventional MLEM with a fixed uniform attenuation map. Wide ranges of image measures were evaluated, including noise, log-likelihood, and region quantification. Uniformity was assessed from bull's eye plots of the reconstructed images. For the appropriate subset size, OSEMIS yielded essentially the same images as EMIS and better than MLEM, but required only one-tenth as many iterations. Consequently, adequate images were available in about fifteen iterations.

Keywords: Iterative reconstruction, ordered subsets, attenuation compensation, myocardial SPECT

1. INTRODUCTION

Recently we have derived a maximum-likelihood expectation maximization algorithm called EM-IntraSPECT¹ (EMIS) for simultaneously estimating SPECT emission and attenuation parameters from emission data alone. EMIS uses the activity within the patient as transmission tomography sources, with which attenuation coefficients can be estimated. However, the reconstruction time is long as compared to a conventional maximum-likelihood expectation maximization algorithm (MLEM)²⁻³. It is well known that ordered subset approach results in accelerating of image reconstruction with acceptable image quality deterioration⁴⁻⁶. The purpose of this study was to evaluate performance of the EM-IntraSPECT (EMIS) algorithm with ordered subsets (OSEMIS) for non-uniform attenuation correction in the chest. The new algorithm, OSEMIS, is a modified EMIS algorithm based on ordered subsets and it has been used in order to accelerate execution of EMIS.

The OSEMIS reconstruction algorithm can be written as:

$$\lambda_k^{n+1} = \lambda_k^n \frac{1}{\sum_{i \in S_0} c_{ik}} \sum_{i \in S_0} \left\{ c_{ik} \cdot \gamma_{ik}^n \frac{Y_i}{\sum_{m \in P_i} \lambda_m^n \cdot c_{im} \cdot \gamma_{im}^n} + c_{ik} (1 - \gamma_{ik}^n) \right\} \quad (1)$$

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$$\mu_{k,lower}^{n+1} = \frac{\sum_{i \in R} \sum_{k0} \sum_{j \in P_i, j \leq k} \lambda_j^n c_{ij} (\gamma_{ijk}^n - \gamma_{ijk+1}^n)}{\frac{1}{2} \sum_{i \in R} \sum_{k0} \sum_{j \in P_i, j \leq k} \left\{ 2\lambda_j^n c_{ij} \gamma_{ijl_i}^n \left[\frac{Y_i}{\sum_{n \in P_i} \lambda_n^n c_{in} \gamma_{inl_i}^n} - 1 \right] + \lambda_j^n c_{ij} (\gamma_{ijk}^n + \gamma_{ijk+1}^n) \right\} l_{ijk}} \quad (2)$$

The meaning of used symbols is as follows:

- i projection subscript,
- J_i number of pixels in the ray I
- j pixel subscript ($j < J_i$),
- P_i set of pixels contributing to projection i ,
- S_0 subset of the projection bins corresponding to a particular set of views,
- R_{k0} subset of projections that belongs to S_0 to which pixel k contributes,
- Y_i total (random) number of photons recorded by the detector bin i ,
- λ_j^n current estimate of source intensity of pixel j (*i.e.* the mean number of photons emitted by pixel j),
- μ_j^n current estimate of linear attenuation coefficient of pixel j ,
- l_{ijm} the path length in the pixel m , *i.e.* the length of the line $j-i$ intercepted by pixel m (in ray-tracing we assume that $l_{ijm} \cong l_{im}$ where l_{im} is the fraction of the ray from the center of bin i intercepted by pixel m)
- γ_{ijm}^n probability of surviving attenuation between the source in the center of pixel j and the boundary of pixel m , for the photon heading towards the detector bin i , evaluated using the current vector of parameter estimates μ^n ,
- c_{ij} known probability (corrected for the decay rate and the time interval of i th projection) that photon leaving pixel j is directed toward detector bin i .

We want to emphasize that summation in Eqs. 1 and 2 is performed over a subset S_0 of the projection bins corresponding to a particular set of views. The images are updated after user-specified number of projection views (OS size) that form the subset S_0 . The OS size may vary from unity (the smallest possible) to the number of acquired views (the largest possible).

2. METHODS

Emission Tc-99m SPECT data were acquired over 360° in a non-circular orbit (pixel size 7.12 mm, 64x32 matrix, 120 views, 10 s/view) from a physical chest phantom. The phantom contained cold “lungs” and “spine” and hot “thorax” cavity, and hot left ventricle “myocardium”. Total activity in the “thorax” cavity was 5.1 mCi (0.85 μCi/ml) and 1 mCi in the “myocardium”. A normal heart was modeled.

OSEMIS was quantitatively evaluated in comparison to EMIS and a conventional MLEM with a fixed uniform attenuation map. The following measures image measures were evaluated: (i) log-likelihood for a selected slice containing “heart”, (ii) three-channel-wide lateral and A-P (anterior-posterior) profiles, (iii) regional quantification for the modeled lungs, spine, soft tissue and bone, (iv) image noise, using a standard deviation in 100 pixels in the center of the “thorax” cavity, (v) uniformity of the activity distribution in the modeled myocardium was evaluated using bull's eye plots of the reconstructed images. The EM-IntraSPECT with OS=120, OSEMIS were used for image reconstruction. A conventional MLEM²⁻³ with OS=120 was also used for comparison.

3. RESULTS

A qualitative evaluation of reconstructed images demonstrates that OSEMIS converges much faster than original EMIS code. EMIS required about 100 iterations to produce adequate image (low-resolution), whereas only two iterations of OSEMIS with OS=5 produced quite similar images. The quality of the reconstructed images improved with the OS size, however more iterations were required to obtain adequate

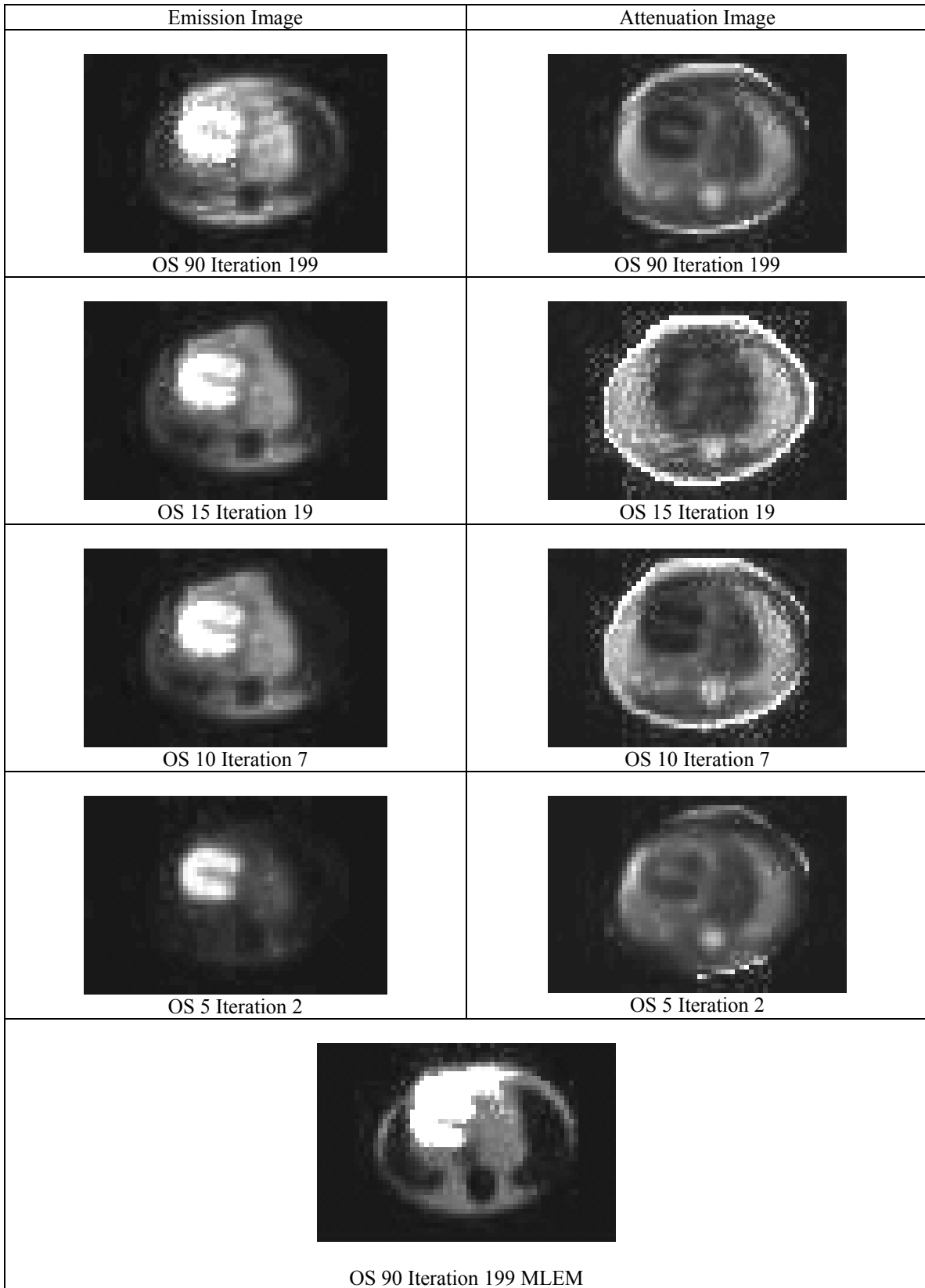


Fig. 1. Reconstructed Transaxial images of slice 9 after iteration 199, 19, 7 and 2 obtained for OS 90, 15, 10, and 5, respectively.

images. He have determined that for the current experimental conditions the reconstruction has to be stopped at iteration 2, 7, 19 and 199 for OS size 5, 10, 15, and 90 (i.e. maximum), respectively. The obtained transaxial images are shown in Fig. 1. For comparison, we reconstructed also the full set of views (OS=90) using MLEM.

The log-likelihood calculated for slice 9 containing the “heart” is shown in Fig. 2. It was calculated at each update denoted here as a subiteration. Generally, increased loglikelihood implies higher resolution, more accurate ROIs, and more image noise. We observe that loglikelihood increases monotonically in EMIS (i.e. OS=90) and MLEM. However, it is much higher for EMIS as compared MLEM. For all smaller subsets the loglikelihood is a non-monotonic function of subiteration. It can be seen that for OS=15 at low iterations it is actually higher than OS=90.

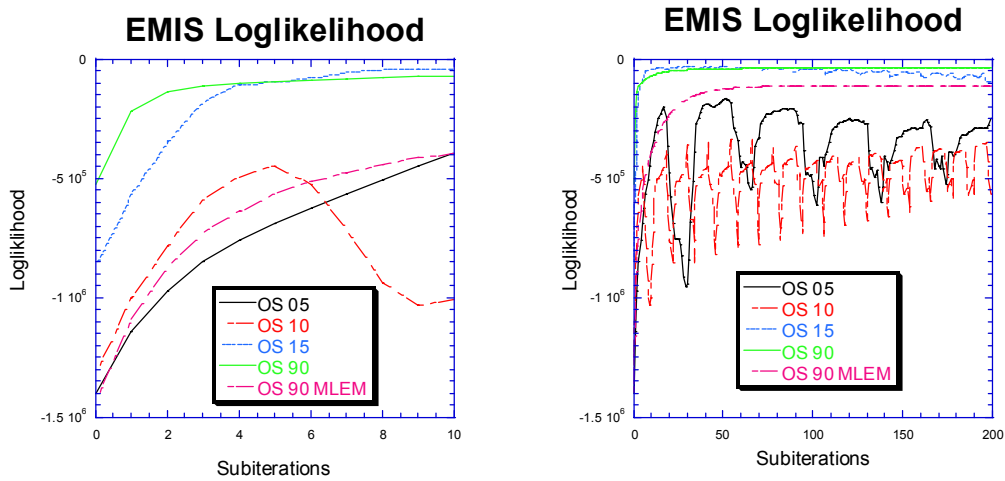


Fig. 2. The log-likelihood calculated for slice 9.

Image noise, obtained using a standard deviation in 100 pixels ROI located in the center of the “thorax” cavity is shown in Fig. 3. For EMIS (OS=90) and OS=5 it increases monotonically with iterations while for OS=10 and OS=15 at low iterations we observe decrease of noise followed by the increase in noise at higher iteration. OS=5 exhibits the highest noise level.

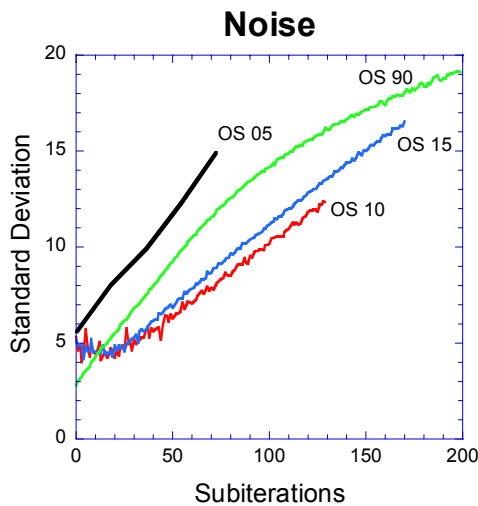


Fig. 3. Image noise, obtained using a standard deviation in 100 pixels ROI.

The three-channel-wide lateral and A-P (anterior-posterior) are shown in Fig. 4. It shows that OS=15 at 20 iterations creates profiles that are quite close to OS=90 at iteration 200.

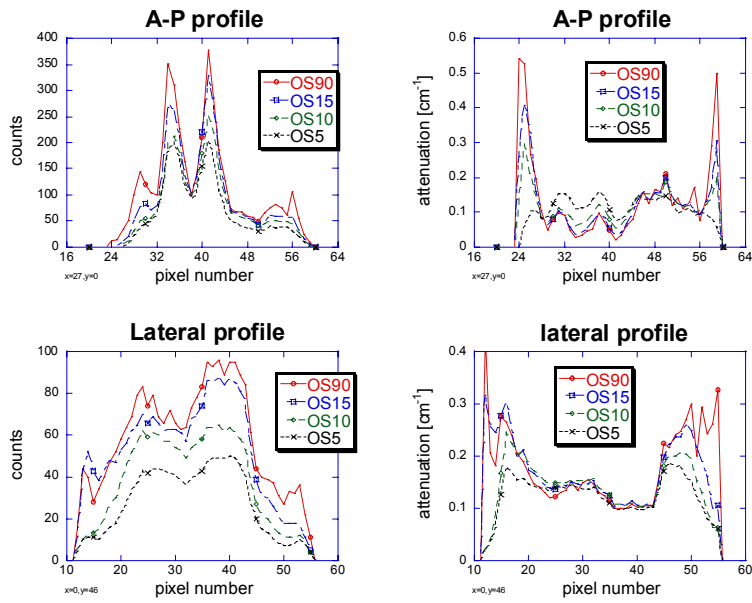


Fig. 4. The three-channel-wide lateral and A-P (anterior-posterior) and lateral profiles.

Regional quantification for the modeled heart and bone is shown in Fig. 5. It demonstrates that only EMIS (OS=90) converges to a mean total activity in the heart and in the spine. The smaller OS size results in monotonically increasing total activity in these ROIs.

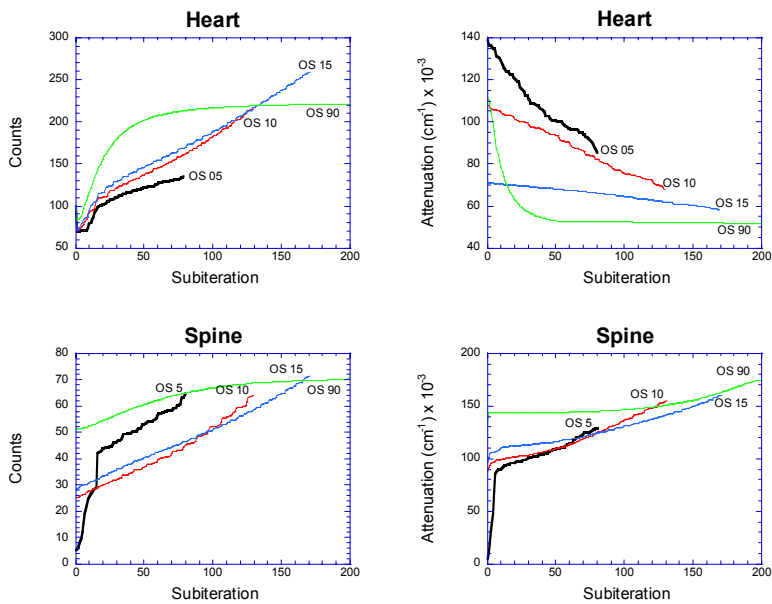


Fig. 5. Regional quantification for the modeled heart and bone.

Uniformity of the activity distribution in the modeled myocardium was evaluated using bull's eye plots of the reconstructed heart images. We observe improved uniformity in EMIS as compared to MLEM. The uniformity deteriorates with decreasing OS size.

CONCLUSIONS

For the appropriate subset size, OSEMIS yields essentially the same images as EMIS and better than MLEM. Consequently, adequate images might be available in about fifteen to twenty iterations.

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