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The Effect Of Post-Reconstruction Gaussian Filter On Image Quality Of Iterative Reconstruction In SPECT/CT

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Abstract: One of the medical imaging modalities used in nuclear medicine is Single Photon Emission Computed Tomography/Computed Tomography (SPECT/CT). SPECT/CT can produce gamma ray distribution images and show the location of radionuclides in the patient's body. SPECT/CT images are obtained from a reconstruction process, one of which is the iterative reconstruction method. Iterative reconstruction is divided into two algorithms, namely the Maximum Likelihood Expectation Maximization (MLEM) algorithm and the Ordered-Subsets Expectation Maximization (OSEM) algorithm. This study aims to evaluate the addition of a post-reconstruction Gaussian filter on the image quality of SPECT/CT reconstruction and to compare the image quality produced from low and high iterations in reconstruction. This study is a retrospective descriptive study using 20 thyroid scintigraphy patients using the SPECT/CT modality. Sinogram data from 20 patients will be reconstructed using the MLEM and OSEM algorithms with low iterations (4 iterations) and high iterations (30 iterations) and the addition of a post-reconstruction Gaussian filter. Image quality was evaluated based on the calculation of the Contrast to Noise Ratio (CNR) and Signal to Noise Ratio (SNR). The results showed that image quality with low iterations was higher than that with high iterations in iterative reconstruction without filters. The addition of a post-reconstruction Gaussian filter can improve the image quality of iterative reconstruction. The average SNR at low iterations is 235.62 (MLEM) and 215.72 (OSEM), while the average CNR is 232.06 (MLEM) and 212.83 (OSEM). At high iterations (30i), the average SNR is 87.59 (MLEM) and 34.12 (OSEM), and the average CNR is 86.31 (MLEM) and 33.62 (OSEM). Image quality in the MLEM algorithm is more optimal than in the OSEM algorithm, but it takes longer than the OSEM algorithm. Therefore, it can be concluded that the OSEM algorithm with low iterations and the addition of a post-reconstruction Gaussian filter can be used in clinical examinations.

Keywords: Effect, Post-Reconstruction, Gaussian Filter, Image Quality, Iterative Reconstruction, SPECT/CT.

I. INTRODUCTION

Medical imaging modalities that can produce three-dimensional images of gamma ray distribution are called Single Photon Emission Computed Tomography (SPECT). The disadvantage of SPECT is that it cannot directly produce detailed anatomical images, so the latest advancement is SPECT combined with Computed Tomography (CT) (Zacho et al., 2017). SPECT provides functional information about organs and tissues that can detect abnormalities before anatomical changes occur. Meanwhile, images from CT show the location of radionuclides in the patient's body in more detail (Bouchareb et al., 2024). SPECT/CT in medicine is used after undergoing a reconstruction process using two algorithms, namely analytical and iterative reconstruction algorithms. The iterative reconstruction algorithm has several advantages over the analytical reconstruction algorithm (Zhao et al., 2022). Iterative reconstruction algorithms can be readily modeled due to attenuation and scatter inhomogeneities. Iterative reconstruction algorithms can also integrate physical data into the reconstruction process.

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Maximum Likelihood Expectation Maximization (MLEM) and Ordered-Subsets Expectation Maximization (OSEM) are the most commonly used iterative reconstruction algorithms. MLEM uses all projection data in each iteration, while OSEM only uses a specific subset of projection data in each iteration. The image quality produced by iterative reconstruction can be affected by iteration (Alqahtani et al., 2021; Zeraatkar et al., 2017). Both Gaussian and Butterworth filters can be used to reduce noise in the reconstructed image. Gaussian filters have a higher lesion detection rate than Butterworth filters (Wikberg et al., 2023). In a clinical context, image quality is very important for diagnostics, so it is necessary to evaluate image quality parameters.

Two image quality parameters are Signal to Noise Ratio (SNR) and Contrast to Noise Ratio (CNR). SNR measures the strength of the signal relative to noise in an image, while CNR measures the contrast between objects and the background, taking noise into account. According to Zeraatkar et al. (2017), Alqahtani et al. (2021), and Wikberg (2023), additional research is needed to investigate the effect of quantity on the reconstruction process using the MLEM and OSEM algorithms. In addition, the addition of a post-reconstruction Gaussian filter process also needs to be considered so that small lesions can be detected properly.

II. RESEARCH METHOD

This study used secondary data reprocessed from Dr. Hasan Sadikin General Hospital. Axial cross-sectional images from SPECT/CT hybrid scans served as the study objects. The total sinogram data used comprised 20 patients who met purposive inclusion criteria. The main focus of the study was the evaluation of SPECT/CT image quality in patients undergoing thyroid scintigraphy. Image acquisition, image reconstruction, application of a post-reconstruction Gaussian filter, and image quality assessment were parts of this study.

Image reconstruction was performed using the MLEM and OSEM algorithms, which depend on the number of iterations, and reconstructions with different iteration counts were combined with the addition of a Gaussian filter post-reconstruction. This study evaluates the effect of high and low iterations on iterative reconstruction. The study began by collecting 20 sinogram datasets from patients who underwent thyroid scintigraphy using the radiopharmaceutical 99mTc-pertechnetate as the gamma radiation source. Sinogram data from scans using SPECT/CT were processed through image reconstruction to produce tomographic images. The collected data consist only of sinograms from thyroid scintigraphy patients with the following criteria:

1. Radiopharmaceutical dose : 3–10 mCi
2. Acquisition time per projection : 10–30 seconds per projection
3. Number of projections : 60–120 projections with 360° rotation
4. Collimator : Low Energy High Resolution (LEHR)

The MLEM and OSEM algorithm reconstruction methods were used in the direct image reconstruction process at Dr. Hasan Sadikin Central General Hospital using a computer connected to the SPECT/CT modality. Image reconstruction was performed with low iterations (4i) and high iterations (30i); however, an additional subset specification was applied in the OSEM reconstruction, namely 8 subsets for both low and high iterations. Reconstruction was performed using Xeleris software. After reconstruction, the reconstructed images were subjected to a post-reconstruction Gaussian filter to improve image quality. The Full Width at Half Maximum (FWHM) in millimeters is the parameter set for the post-reconstruction Gaussian filter in Xeleris software. FWHM is the measure of the width of the Gaussian curve at half of its peak, indicating the degree of smoothing applied to the image. In this study, the FWHM used was four millimeters. After all procedures were completed, the resulting images were sent in DICOM format so they could be further assessed for image quality parameters.

MATLAB software was used to assess image quality parameters, which involved calculating SNR and CNR. Digital images in DICOM format were entered into the program and then processed to assess image quality parameters. First, the image was entered and the ROI was selected. The ROI consists of a signal ROI and a background ROI. The signal ROI is located in all areas that encompass high radiopharmaceutical accumulation on SPECT images, while the background ROI is located in an area that is considered homogeneous, such as non-thyroid neck soft tissue. The shape and dimensions of the background ROI are similar to the signal ROI.

The next process is to calculate the average signal value, the average background value, and the noise standard deviation. The noise standard deviation is obtained by extracting all pixel values from the background ROI. The noise standard deviation in the background ROI is chosen to avoid measurement bias due to partial volume effects (PVE). PVE occurs by magnifying the intensity of small objects, which are proportional to the spatial resolution of the scan or smaller than the actual size. The PVE phenomenon is the appearance of image blur caused by limited spatial resolution. Blur causes overlap between regions. Images from hot regions, such as tumors, appear larger and dimmer. Equations 2.1 and 2.2 are used to calculate the SNR and CNR values (Yucel-Finn et al., 2024). The calculation of image quality parameters is performed for each reconstructed image, both at different iterations and after the application of a Gaussian filter. After the SNR and CNR values are obtained, a statistical test is performed to strengthen the results obtained from the SNR and CNR calculations. The results obtained from the SNR and CNR calculations and the statistical test will be subjected to data analysis.

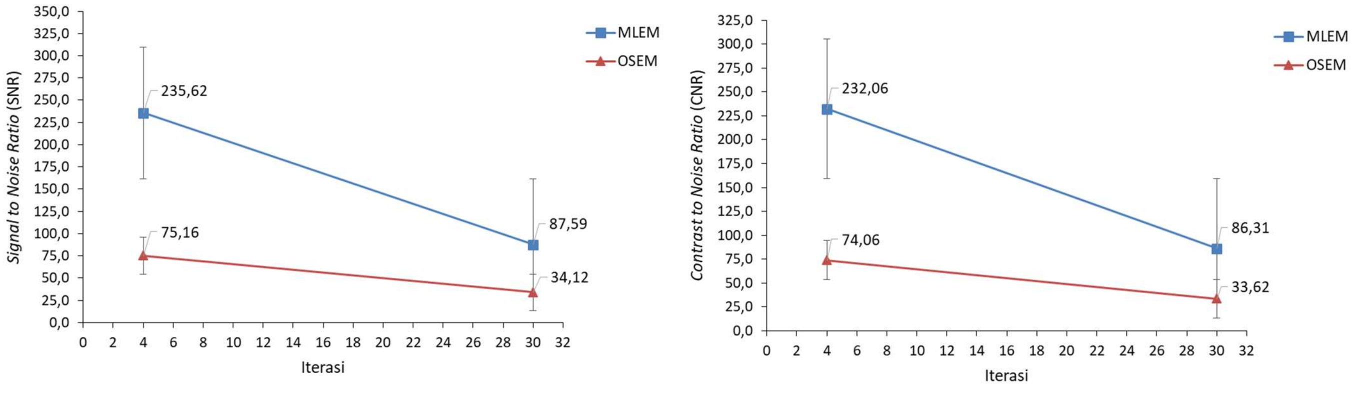
$$SNR = \frac{\mu_{Sinyal}}{\sigma_{Background}} \tag{2.1}$$

$$CNR = \frac{\left|\mu_{Sinyal} - \mu_{Background}\right|}{\sigma_{Background}} \tag{2.2}$$

III. RESULTS AND DISCUSSION

In this study, quantitative assessment was used to evaluate the image quality produced from MLEM and OSEM reconstruction without filters and with Gaussian filters. The image quality evaluated included images reconstructed from 20 thyroid scintigraphy patients using the GE NM/CT 870 CZT SPECT/CT modality. Xeleris software at Dr. Hasan Sadikin General Hospital in Bandung was used to obtain sinogram data from twenty patients.

The calculation of SNR and CNR values in this study was used as a quantitative assessment. In each reconstruction, SNR and CNR were calculated with a predetermined number of iterations. Figure 3.1 shows the average SNR and CNR values of twenty thyroid scintigraphy patients obtained in each reconstruction.



(a) (b)

Figure 3.1 Relationship between (a) average SNR values and (b) average CNR values at low iterations (4i) and high iterations (30i) of the MLEM and OSEM algorithms

In iterative reconstruction (MLEM and OSEM), the average SNR and CNR values are higher at low iterations (4i) than at high iterations (30i). Low iterations (4i) obtained average SNR values of 235.62 (MLEM), 75.16 (OSEM) and average CNR values of

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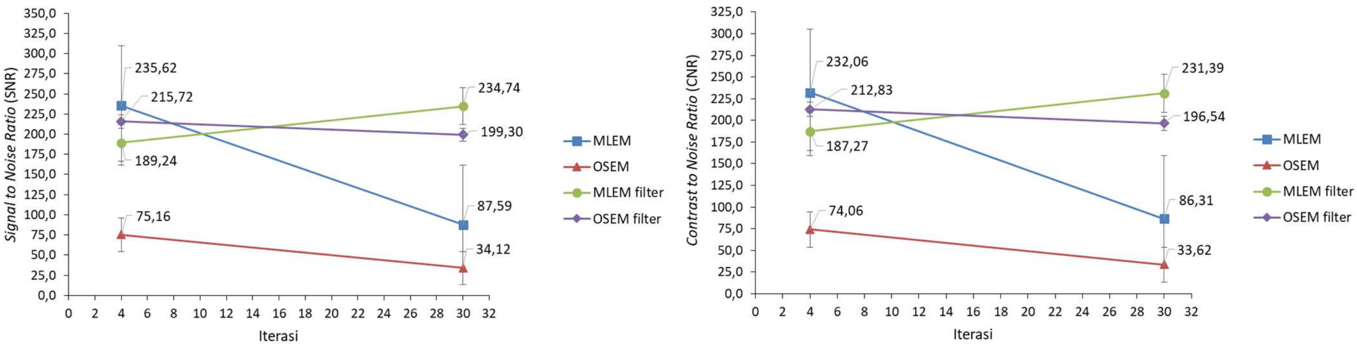
232.06 (MLEM), 74.06 (OSEM). High iterations (30i) obtained average SNR values of 87.59 (MLEM) and 34.12 (OSEM) and average CNR values of 86.31 (MLEM) and 33.62 (OSEM).

At low iterations (4i) high average SNR and CNR values are obtained, although the signal is spread over several pixels causing the image to appear blurred. This is because at low iterations the noise level is still minimal and the signal intensity has not yet reached the optimal convergence point. As iterations increase, the MLEM and OSEM algorithms refocus the signal back to the original source. The intensity values (counts) increase and approach the true values (convergence), but the algorithms tend to interpret small random variations as real signal and amplify them. As a result, noise dominance at high iterations (30i) reduces the SNR and CNR values again even though the signal has stabilized.

Statistical tests were also conducted to reinforce the obtained results. A Friedman test was performed on the quantitative assessments of SNR and CNR for all images and showed a highly statistically significant difference between iteration groups ($p < 0.05$). The quantitative assessments from the SNR and CNR calculations are consistent with the Friedman test results, indicating that the number of iterations significantly affects SNR and CNR values in both MLEM and OSEM reconstructed images.

Based on the SNR and CNR obtained, it shows that the quality of iterative reconstruction images decreases as the iteration increases. Higher iterations can significantly amplify noise. The average SNR and CNR values are significantly influenced by the number of iterations (Kupitz et al., 2021). The decline in image quality at high iterations is caused by an increase in background noise, even though the signal in the organ is stable. Iterative reconstruction without filters produces optimal image quality at low iterations (Alqahtani et al., 2021).

In the previous discussion, it was explained that increasing the number of iterations in MLEM reconstruction without filters can increase noise in the image. In this study, a post-reconstruction Gaussian filter with FWHM 4 mm was added to reduce noise in the image, which means that image quality can be improved. The effect of adding a post-reconstruction Gaussian filter on the average SNR and CNR values is illustrated in Figure 3.2.



(a) (b)

Figure 3.2 Comparison of (a) average SNR and (b) average CNR values with post-reconstruction Gaussian filters in the MLEM and OSEM algorithms

The average SNR and CNR values without filters and with post-reconstruction Gaussian filters are different, as shown in Figure 3.2. By adding a post-reconstruction Gaussian filter at a low iteration (4i), the quality of the iterative reconstruction image improves. The average SNR values at low iterations are 235.62 (MLEM) and 215.72 (OSEM), while the average CNR values are 232.06 (MLEM) and 212.83 (OSEM). At high iterations (30i), the average SNR value is 234.74 (MLEM) and 199.30 (OSEM), and the average CNR value is 231.39 (MLEM) and 196.54 (OSEM).

The Image quality of the OSEM algorithm can degrade as the number of iterations increases, even with the addition of a Gaussian filter post-reconstruction. This is shown in Figures 3.2a and 3.2b, which display decreasing SNR and CNR with increasing iteration count. The decline in image quality is also caused by increased background noise and noise amplification by the OSEM algorithm. Conversely, the MLEM algorithm shows increases in SNR and CNR from low iterations (4i) to high iterations (30i). The MLEM algorithm has a slower convergence rate compared to OSEM, so at high iterations (30i) MLEM is still in the phase of forming optimal signal contrast and has not reached extreme noise saturation. MLEM also has the lowest vulnerability to noise amplification (Zeraatkar et al., 2017), which causes the mean SNR and CNR values to increase with additional iterations (Figures 3.2a and 3.2b).

Statistical tests were also performed again to determine the effect of post-reconstruction Gaussian filters on SNR and CNR values. The statistical tests began with the Friedman test, which showed that the number of iterations could also affect the quality of MLEM reconstruction images (both with and without filters) and OSEM reconstruction without filters. A p-value < 0.05 in the Friedman test shows that image quality in iterative reconstruction is very sensitive to changes in iteration. However, in OSEM reconstruction with post-reconstruction Gaussian filters, the statistical test results show a significant p-value > 0.05. This value proves that the addition of a post-reconstruction Gaussian filter to OSEM produces very high image quality stability.

The next statistical test, the Wilcoxon test, used image data from 20 thyroid scintigraphy patients. The Wilcoxon test was performed to compare pairs of data (SNR without filter vs. SNR with Gaussian filter, etc.). The Wilcoxon test results show that the addition of a Gaussian filter provides a very significant difference for SNR and CNR in MLEM and OSEM reconstructions ($p < 0.05$). Statistical tests show that there is no difference in quality between images with post-reconstruction Gaussian filters and those without filters.

The addition of a post-reconstruction Gaussian filter is able to suppress object/signal noise and background noise (Zhao et al., 2022). Noise suppression performed by the post-reconstruction Gaussian filter causes an increase in image quality, which is indicated by an increase in SNR and CNR values. The addition of a post-reconstruction Gaussian filter allows MLEM reconstruction to continue to improve signal contrast and detail until the optimal quality shift occurs (low iteration to high iteration). The benefit of adding a filter in suppressing noise is much higher than the effect of signal reduction, resulting in optimal image stability and quality (Morphis et al., 2021; Zhao et al., 2022).

Based on Figure 3.1 and Figure 3.2, it can be seen that the optimal quality point obtained by the MLEM algorithm is at a high iteration (30i) with the addition of a post-reconstruction Gaussian filter. Meanwhile, the OSEM algorithm obtains optimal quality at a low iteration (4i). Increasing iterations in iterative reconstruction requires more time (Zeraatkar et al., 2017; Zhao et al., 2022). Therefore, the MLEM algorithm requires more time to obtain optimal image quality compared to the OSEM algorithm. This statement is in line with research conducted by Alqahtani et al., 2021, Lima et al., 2024, and Zhao et al., 2022.

IV. CONCLUSION

The image quality of MLEM and OSEM iterative reconstruction can be influenced by the number of iterations. The MLEM and OSEM algorithms without filters with low iterations (4i) have better image quality than high iterations (30i). Although low iterations (4i) produce good image quality, iterative reconstruction without filters produces high noise. Noise suppression in iterative reconstruction images can be done by adding a post-reconstruction Gaussian filter (FWHM = 4 mm). Noise suppression provides good image quality at both low iterations (4i) and high iterations (30i). The MLEM algorithm achieves optimal quality at 30 iterations with the addition of a post-reconstruction Gaussian filter, while the OSEM algorithm achieves optimal quality at 4 iterations. In a clinical context, the OSEM algorithm with low iterations (4i) is the recommended algorithm for thyroid scintigraphy examinations.

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