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Full Length Research Paper

Comparison between the image qualities obtained with low energy high-resolution (LEHR) and LEGP collimators in single-photon emission computed tomography (SPECT) under implementation of different filters

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The aim of a single-photon emission computed tomography (SPECT) filter is to use the sharpest filter/smooth combination consistent with getting quality images. Fourier filtering technique has been shown to greatly improve image quality in both the spatial and temporal domain. An optimal filter manipulates the image in such a way that the image quality is enhanced without losing the basic components of the input object. Many filters have been developed to recover resolution and suppress noise. Thus, the question of the optimal filter selection has been the subject of this investigation. The selection of proper collimator in many application of SPBCT will contribute to optimal image quality and quantitative information within the characteristics of the imaging equipment .In this study, we compared the results obtained by utilization of low energy high-resolution (LEHR) and low energy general-purpose (LEGP) collimators, under implementation of various filters, to show effect of hardware and software filters on the image quality, and capability of mathematical tools to compensate for the hardware flaw.

Key words: Single-photon emission computed tomography (SPECT), filter, low energy high-resolution (LEHR) collimator, low energy general-purpose (LEGP).

INTRODUCTION

Single-photon emission computed tomography (SPECT) is based on the measurements of gamma rays radiated by some amounts of radionuclide injected into the patient. The radionuclide distribution is obtained by line integrals of exponentially weighted radionuclide distribution to represent attenuation of radiation on its way from a source to the detector.

Mathematical procedure is required for image reconstruction from collection of projection which is made by set of line of response (Zeng, 2001; Kak, 1984). Different types of image reconstruction have been used for this propose. The filtered back projection (FBP) (Laereaet al., 2001) and statistical model based iterative algorithms (Bruyant, 2002) are the two major classes of reconstruction methods. Despite of the fact that there are new techniques of image reconstruction (Kunyansky, 2001; Zeniya et al., 2004); The FBP method is still widely used in clinical setting for its speed and easy implementation (Kak, 1984).

The information in nuclear medicine images is obscured due to the presence of Poisson noise and the finite resolution of the detection system. To obtain optimal image quality and quantitative information, several inter-related factors have important effects on reconstructed single-photon emission computed tomography (SPECT) images. The first of these factors is camera-dependent characteristics such as collimation and solution, uniformity and stability of the COR (center- of-rotation). The second is patient-dependent factors such as positioning (minimization of camera distance) and movement which are often excused. The third is due to reconstruction parameters and corrections including attenuation and scattering, partial volume effects, and filtering which determines the optimum image quantitative information content which can be linked to physiological parameters of interest (Laerea et al., 2001; Cherry et al., 2003). Proper filtering of nuclear data is necessary for both correct image visualization and as a prerequisite for further image processing such as boundary detection (Groch and Erwin, 2000). Many filters have been developed to recover resolution and suppress noise. Filter selection in SPECT image reconstruction poses an implicit trade-off between image smoothness, image contrast and noise texture (Laerea et al., 2001; Madsen and Park, 1985). It is known that the ramp filter provides the greatest contrast and resolution (in a reconstructed image at the expense of poor noise handling). In order to improve detection of either hot or cold lesions, practical experience dictates that some images smoothing must be provided. Thus, the question of the" optimal" filter selection has been the subject of this investigation. Using the proper collimator in any applications reduces the scattered data which degrades the image.Determining the best filter, especially in the presence of peripheral source with respect to the type of collimator will improve the most accurate diagnosis and select the best filter in diagnostic defect size (Cherry et al., 2003). In this study, we have reviewed the effect of LEHR and LEGP collimator for 1-line and 2-line sources under usage of various filters. These results reduce the time of image processing since a proper filter function is often chosen clinically by the tedious and time-consuming process of trial and error.

IMAGING PROTOCOL

Imaging was performed using a double-head ADAC EPIC Vertex model SPECT camera and in the Morvarid nuclear medicine center. Low energy high-resolution and low energy general-purpose collimators were used for imaging. Images were recorded over 180˚ in 128×128 matrices and 16-bit depth with an acquisition time of 60 s per projection and 64 projections. Distance of between shields to UFOV was set at 9.4 cm, step-and-shoot mood, and zoom factor of 2 were used.

PROCESSING

Once, the vial with 2 mm thickness was filled with water containing ^{99m}Tc (10 mCi, 1.4 cc) and fixed in the proper position in the Jaszczak phantom. All the SPECT studies were reconstructed by filtered back projection technique with a Ramp filter; Parzen, Hanning, Hamming (with 9 different filter parameters), Gaussian filter (with 81 different filter parameters), and Butterworth filter (with 63 different filter parameters). In the next step, two resemble vials, similar to the previous step, were prepared. They fixed in the Jaszczak phantom parallels with space of 9.9 cm. The condition of imaging is equal to previous step. In the third step, we use LEGP collimator other than LEHR collimator and the same processing has been repeated.

TYPES OF FILTRATION

Parzen, Hanning and Hamming filter are low pass filter and have only one parameter. We used the values of 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8 and 0.9 for the cutoff frequency. All the aforementioned values were selected blindly to cover the whole range of variables. A total of 27 filtering conditions were considered.

Butterworth filter has also two parameters, cutoff and order. We have used the values of 0.3, 0.4, 0.5, 0.6, 0.7, 0.8 and 0.9 for cutoff frequency and 1, 2, 3, 4, 5, 6, 7, 8 and 9 for order. A total of 63 combinations of cutoff and order were considered.

Gaussian filter is a Band- Pass filter and has two parameter to be adjusted, cutoff frequency and order. We have used the values of 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8 and 0.9 for cut off frequency and 1, 2, 3, 4, 5, 6, 7, 8 and 9 for order, total of 81 combinations of both parameters.

RESULTS

Hanning, Hamming, Parzen

1-line source

LEHR collimator: For all of these filters, in this study, the cut-off frequencies from 0.6 to 0.9 were found to be potentially useful and the best result was obtained by using the cut-off of 0.9 (Figure 1a).

LEGR collimator: Only result 0.9 for cut-off might be potentially useful (Figure 1b), but even in this case, the value of FWHM will be much worse than the previous.

2-line sources

The results with usage of LEHR and LEGP collimator were almost the same as the one with 1-line source (Figure 2), but the value of FWHM in the cut-off frequencies from 0.7 to 0.9 will be constant approximately. Furthermore, the values of FWHM for LEHR collimator are better than the others.

Butterworth filter

1-line source

LEHR collimator: Among all combinations of cut-off and order, the potentially acceptable values range of cut-off and order was found to be 0.4 to 0.9 and 6 to 9, respectively. Our investigation showed that the best FWHM could be obtained using the cut-off frequency of 0.9 and order of 9 (Figure 3a).

LEGR collimator: For all of these filters in this study, the orders from 3 to 9 and 0.4 to 0.9 for cut-off frequency were found to be potentially useful and the best result was obtained by using the cut-off and order of 0.9 and 9, respectively (Figure 3b).

2-line sources

LEHR collimator: Only results from 0.5 to 0.9 for cut-off

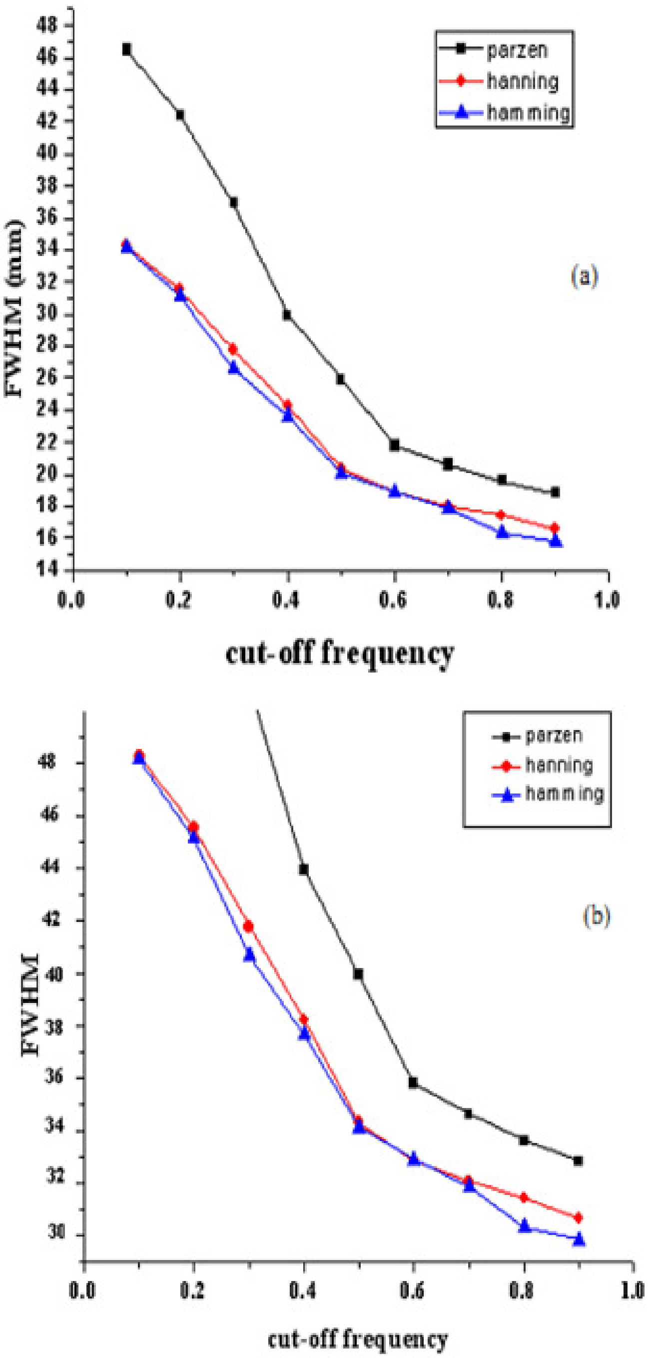

Figure 1. The FWHM of 1-line source image under implementation of Hanning, Hamming, Parzen filters; (a) LEHR collimator, (b) LEGP collimator.

frequency and order from 4 to 10 might be potentially useful. The best FWHM could be obtained using the cut-off frequency of 0.9 and order of 9 (Figure 4a).

LEGP collimator: The results are very similar to using of LEHR collimator, but the value of FWHM in this situation has been increased (Figure 4b).

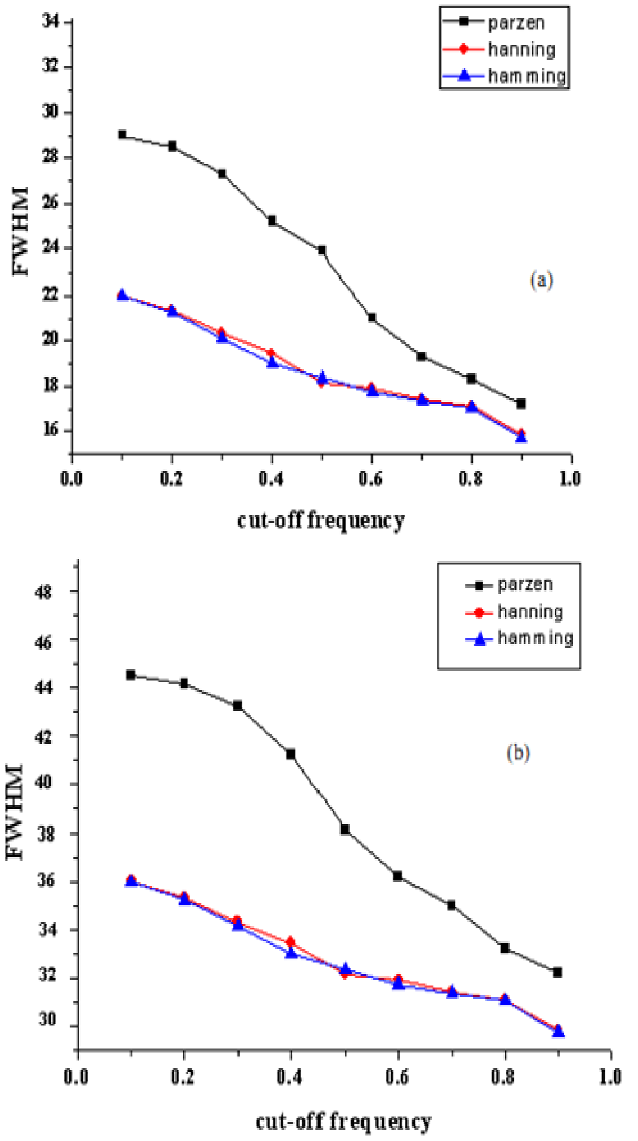

Figure 2. The FWHM of one of 2-line sources image under implementation of Hanning, Hamming and Parzen filters; (a) LEHR collimator, (b) LEGP collimator.

Gaussian filter

1-line source

LEHR collimator: The FWHM results obtained for 1-line source showed that the potentially acceptable range of cut-off and order was found to be 0.8 to 0.9 and 1 to 9, respectively, and the best FWHM could be obtained using the cut-off frequency of 0.9 and order of 9 (Figure 5a).

LEGP collimator: Same situations are dominated, but the best result which is worse than previous is acquired when we select 0.9 for cut-off frequency and 4 to 9 for order values.

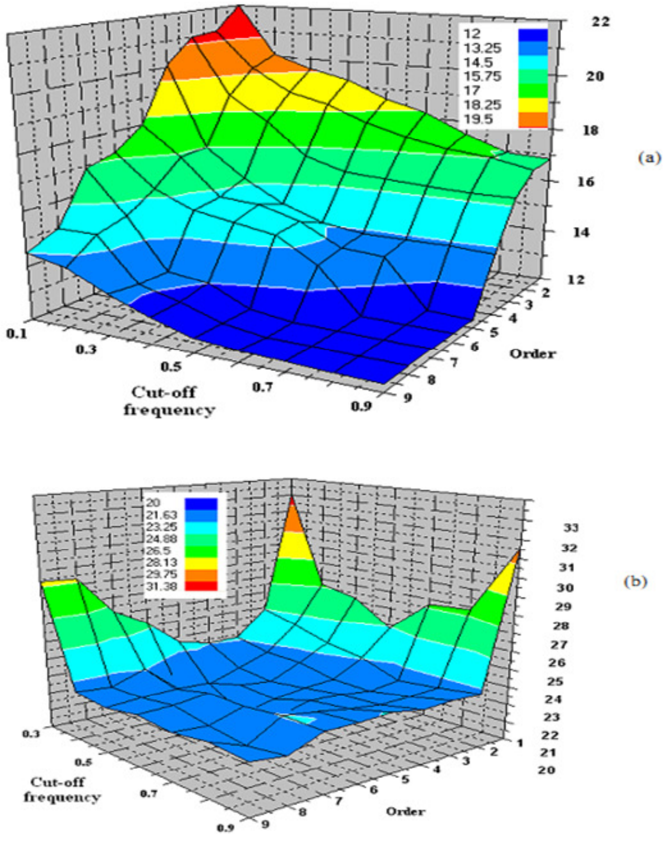

Figure 3. The FWHM of 1-line source image under implementation of Butterworth filter; (a) LEHR collimator, (b) LEGP collimator.

2-line source

LEHR collimator: For the case of 2-line sources, parameter values from 0.5 to 0.9 for cut-off frequency and 1 to 9 for order might be potentially useful. The best FWHM could be found by using cut-off frequency of 0.9 and order of 9 (Figure 6a).

LEGP collimator: Same situations are dominated, but the oscillation in the high cut-off is obvious and in the higher values of cut-off frequency, the fluctuation has been increased (Figure 6b). Finally, the best result could be obtained by using cut-off frequency of 0.9 and order of 9 (Figure 6a).

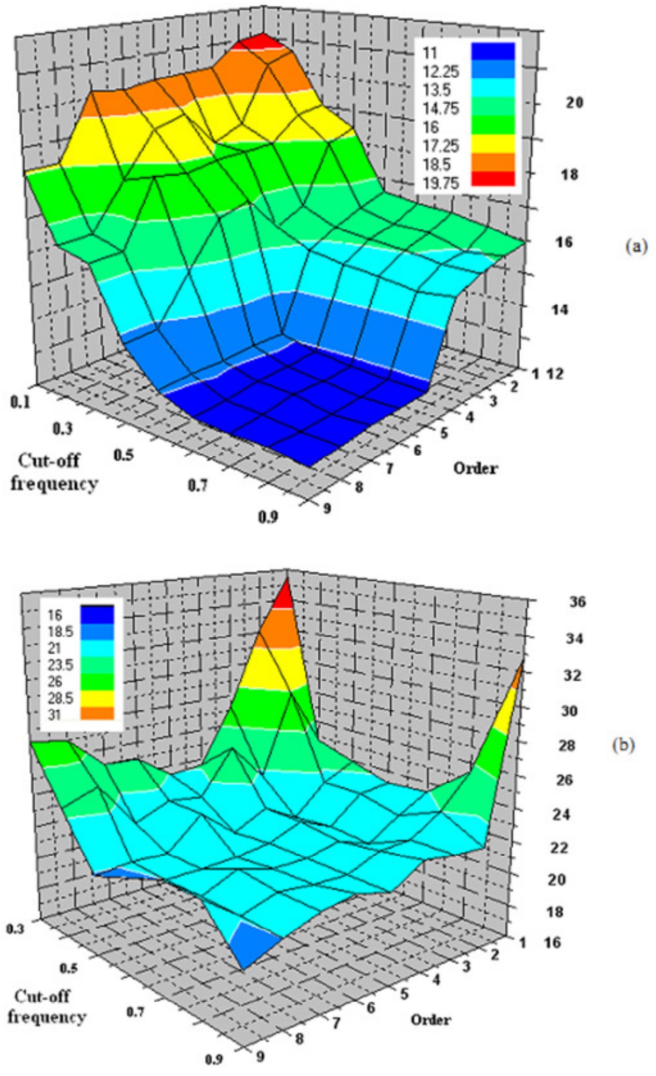

Figure 4. The FWHM of one of 2-line sources image under implementation of Butterworth filter filters; (a) LEHR collimator, (b) LEGP collimator.

DISCUSSION

Hanning, Hamming, Parzen filters

1-line source

Figure 1 for 1-line source under implementation of Hanning, Hamming, Parzen filters show that, for both of collimator, the value of FWHM is improved as expected when the cut-off frequency is increased, but excellence of LEHR collimator is sensible for all comparison, and so, these differences are less obvious as cut-off frequency are increased. Thus, in usage of LEHR collimator in SPECT imaging in high count rate situation, application of cut-off frequency is necessary when we select low pas filters.

2-line source

Calculation of the FWHM for all of the result obtained for 2-line sources under implementation of Hanning, Hamming, Parzen filters (Figure 2) with LEHR and LEGP collimators show that decreasing procedure of values of FWHM resemble 1-line source, but the values of FWHM decreased (Figure 2). On the other hand, improving in image quality is constant in the range of 0.7 to 0.9 in

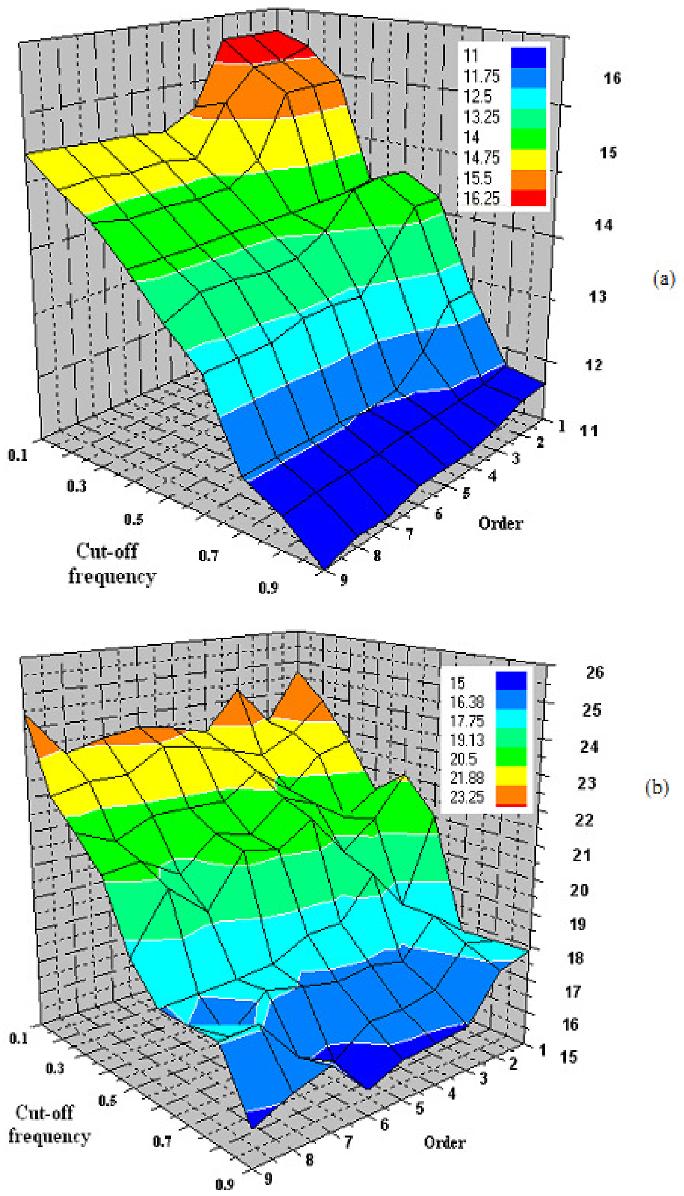

Figure 5. The FWHM of 1-line source image under implementation of Gaussian filter filters; (a) LEHR collimator, (b) LEGP collimator.

either situation. Furthermore, decreasing of FWHM value with increasing of cut-off frequency is less sensible than calculated FWHM of 1-line source image.

Butterworth filter

1-line source

For the line source, with the use of LEHR collimators (Figure 3) with increasing of the cut-off frequency, FWHM values improved, and with the increasing of the order, the effect of changing in cut-off frequency values is more obvious. The value of FWHM is almost constant for the 0.5 to 0.9 and 5 to 9 for cut-off frequency and order, respectively. The best value for FWHM in this range is about 12 mm.

Results obtained from the use of LEHR collimator (Figure 3b) are much better than the results obtained from the use of LEGP collimator (the best value of FWHM is about 20 mm). The results show that the values of FWHM in the extend range of cut-off frequency and order (3 to 9 for order and 0.4 to 0.9 for cut-off frequency) are relatively constant, but the results are not remarkable in the low order and cut-off frequency.

Comparison of results obtained by use of the two collimators under implementation of Butterworth filter show that whole result obtained by use of LEHR collimator is much better than the best result obtained by the use of LEGR collimator. Indeed, because of increasing in the septa holes diameters in the LEGP collimator as compared with LEHR collimator, acceptance potential of scatter event has been increased and then the spatial resolution of SPECT system has been declined. For the both collimator, region with the constant value for the FWHM diagram exists but this region for LEGP collimator is bigger than another.

2-line source

Calculation of the FWHM for all of the result obtained from 2-line source image for Butterworth filter (Figure 3a) show an improvement in FWHM as the cut-off frequency and order increases, and similar to 1-line source, existence of plateau area in the specific region of diagrams is obvious. This area for LEHR collimator is set in the ranges from 0.6 to 0.9 for cut-off frequency and for the order in the ranges from 6 to 9. For a desired value of order, increase in the cut-off frequency causes decrease in FWHM similar to 1/ (cut-off) behavior. And further, in the lower cut-off frequency (<0.4), the values of FWHM are approximately constant in different value of order.

Same behavior for FWHM diagram existed in the use of LEGP collimator, but the area of plateau for this collimator (0.5 to 0.9 and 4 to 9 for cut-off frequency and order, respectively) is bigger than later. Remarkable point for this study is that the worth result obtain by using the LEHR collimator is always better than the obtained results by use of LEGP collimator under implementation of Butterworth filter with various parameter.

Gaussian filter

1-line source

Same behavior for LEHR and LEGP collimator in Figure 5 are obvious. This figures show that for specified values

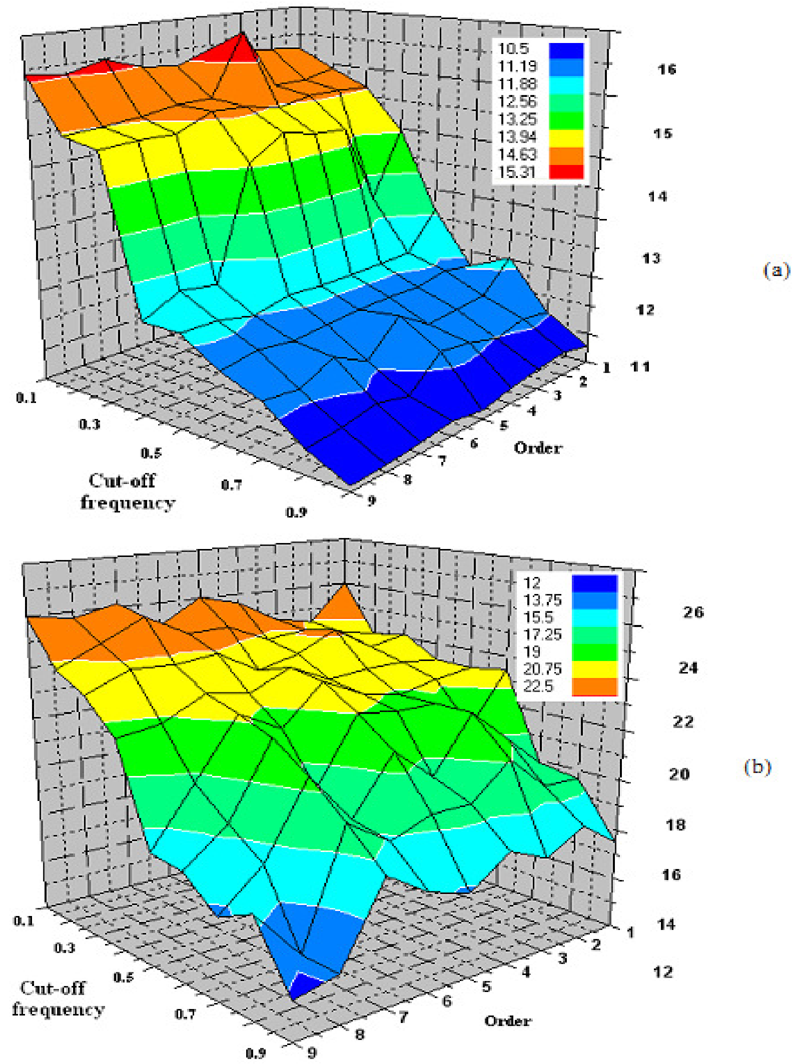

Figure 6. The FWHM of one of 2-line sources image under implementation of Gaussian filter; (a) LEHR collimator, (b) LEGP collimator.

the cut-off frequency (especially in the range of 0.5 to 0.9), the variation of order do not have any effect on FWHM for line source image, therefore the figure is more dependent on the cut-off frequency than order. This fact demonstrate that in the high count density situation for the using band pass filters such as Gaussian filter the effective parameter that influence on spatial resolution is cut-off frequency.

The excellence of LEHR collimator is explicit in these figures than in LEGP collimator. The best result for FWHM is obtained with the usage of LEGP collimator which is achievable with 0.9 and 9 for the cut-off frequency and order, while the worse value of FWHM is obtained with LEHR collimator.

Remarkable point for comparison between images obtained by use of two collimators is that with the increase in cut-off frequency, differences between values of FWHM have been decreased. The power of filtering is revealed by this fact as the implementation of filtering on the images obtained by using of two collimators causes to removing corrupt event accepted by LEGP collimator relevant to LEHR collimator and then, spatial resolution improved.

2-line source

For 2-line sources in Figure 6, same situation similar to 1-line source existed, but for LEGP collimator, the fluctuation behavior is increased as the cut-off frequency increased, whereas variation of FWHM for LEHR in comparison with LEGP collimator did not exist. Increasing the cut-off frequency causes the decrease of FWHM similar to 1/ (cut-off) manners.

The comparison between diagrams (a) and (b) in Figure 6 show that better results are obtained for implementation of LEGP collimator and selection of 0.8 to 0.9 for cut-off frequency and 7 to 9 for order in comparison with using of LEHR collimator with 0.1 to 0.4 for cut-off. This is a noticeable subject for the use of mathematical procedure in improving of image quality in nuclear medicine tomography imaging, because we compensated the degradation of spatial resolution of image obtained by SPECT system equipped with general purpose collimator, with software methods.

Diagrams in Figures 5 and 6 shows that in the use of Gaussian filter, the operator could change the cut-off frequency (rather than order) to achieve the best images quality, if high count rate situations existed.

Conclusion

Results show that when using LEGP collimator for SPECT imaging, the best result for image quality a line source is achieved by Gaussian filter. Remarkable point for this study is that the value of FWHM image acquired with SPECT system equipped with LEGP collimator under implementation of Gaussian filter is better than the value of FWHM image acquired with SPECT system equipped with LEHR collimator under implementation of Parzen or Hamming filters and the power of filtering is revealed by this fact in removing corrupt events accepted by LEGP collimator. The different function of the Butterworth filter for 1-line source in comparison of other filters is noticeable. Calculation of the FWHM for all of the results obtained for 1-line source and 2-line sources show an enhancement in FWHM as the cut-off frequency increases. This improvement occurred because of using 10 mCi line source which cause high counting rate. This implies that if the high count density is dominated, the best spatial resolution is acquired in high cut-off frequency filters.

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