Optimum Energy Window In Liver Scintigraphy

Alireza Sadremomtaz, Mohaddeseh Saber Zidehsaraei

Abstract: In liver scintigraphy, radioactive tracers, in addition to liver, are accumulated in other organs such as spleen. It leads to the presence of secondary source, which affects image quality. Therefore, knowing the influence of the noise arising from the secondary source and trying to reduce the additional data is necessary. In nuclear medicine imaging, using of energy window is a useful way to reduce the noise. In this paper, we try to find an optimum energy window to reduce the noise for two different low energy collimators. Liver scintigraphy images with and without activity in spleen were simulated by SIMIND software with different energy window percentages and with Low-Energy High-Resolution (LEHR) and Low-Energy General-Purpose (LEGP) collimators. We used ^{99m}Tc with activity of 190 MBq. Spleen was outside of the camera field of view so that just its noise effects on the liver image is examined. Finally, the images of liver with activity in spleen were compared with that without activity in spleen by MATLAB code.

Keywords: energy window, image quality, noise, SIMIND, simulation.

1. Introduction

ONE of the most important issues in nuclear medicine imaging is image quality, which is restricted by different elements such as 1) spatial resolution, 2) contrast and 3) noise. Noise can be statistical or structured. In this paper, we focus on structured noise. Structured noise refers to nonrandom variations in counting rate that are superimposed on and interfere with perception of the object structures of interest. Some types of structured noise arise from the radionuclide distribution itself [1]. For example in liver scintigraphy, in addition to liver, radiopharmaceutical is accumulated in other organs such as spleen or gallbladder. Methods, protocols and chemical compound of radiopharmaceutical used depend on the diagnostic aim of liver scintigraphy. In general imaging of liver, the secondary source of activity is usually spleen [2]. Although specialists may use the information of radiopharmaceutical deposition in spleen, but it increases the noise of image and it can cause misinterpreting of liver image. The purposes here are to examine the effect of energy window percentage on additional noise resulted from the secondary source and the effect of collimator on choosing optimum energy window.

2 Methods and Materials

2.1 Softwares and Phantoms

We used simulation for our study because of the high costs and limitations in experimental studies. Monte Carlo simulation is an appropriate method for simulation of nuclear medicine imaging. We used SIMIND software, which is developed by professor Ljungberg and colleagues in 1989 at Lund University in Sweden and has two main program called CHANGE and SIMIND [3-6].

The CHANGE program provides a way of defining the system which should be simulated and provides an output file with *.SMC suffix. Then SIMIND uses this file for simulation and produce different output files [7]. We used version 4.9 of SIMIND for 32-bit windows and original Zubal torso phantom known as vox-man with 0.4cm thickness of layers [8-9]. It is a 128×128×243 Integer*1 coded phantom with no arms and legs [10-11]. In our simulation, phantom's head is placed in x-axis direction and camera is above z-axis. We used ^{99m}Tc, which is a common radionuclide in liver scintigraphy. Energy resolution of camera is considered 9.8%, corresponding to clinical conditions [12]. Activity in liver is 190 MBq. Images were simulated with and without activity in spleen (as sample and reference images respectively) in different energy windows from 5% to 30% with LEHR and LEGP collimators. Considering only the noise from spleen, it was placed out of camera field of view. We set the random sampled seed value false in CHANGE program so there is no statistical noise in our simulation. Other settings and collimators information are shown in table I and II.

TABLE I.
Simulation System Settings in CHANGE

system settings	
crystal size	26×32cm^2
crystal thickness	1.59cm
photonic history	1000000
image dimensions	64×64
density map dimensions	128×128
pixel size in simulated image	0.385cm
pixel size in density map	0.34cm

- *Alireza Sadremomtaz, Associated professor of nuclear physics, University of Guilan, Rasht, Iran.*
  E-mail: sadremomtaz@yahoo.co.uk
- *Mohaddeseh Saber Zidehsaraei, MSc of nuclear physics, University of Guilan, Rasht, Iran.*

TABLE II.
SIMULATION SYSTEM SETTINGS IN CHANGE

Collimators	LEGP	LEHR
collimator code	GV-LEGP	GV-LEHR
collimator type	Parallel	parallel
hole shape	Hexagonal	hexagonal
hole size x	0.19cm	0.14cm
hole size y	0.212cm	0.157cm
septal	0.02cm	0.02cm
collimator thickness	3.5cm	3.28cm

The format of images was changed by XMedcon software to a readable format for MATLAB [13]. By subtracting sample images from reference images in MATLAB, we obtained the spleen structured noise images for each energy window.

2.2 Image Quality Evaluation Parameters

We compared the sample images of each energy window with its reference image in MATLAB by two image quality parameters: mean square error (MSE) and Power Signal to Noise Ratio (PSNR). MSE measures the average error squared. The error is the amount by which the estimator differs from the quantity to be estimated [14]. Lower MSE shows better image quality. $x_{j,k}$ and $x'_{j,k}$ are reference ang sample image matrix.

$$MSE = \frac{1}{MN}\sum_{j=1}^{M}\sum_{k=1}^{N}\left(x_{j,k} - x'_{j,k}\right)^2 \quad (1)$$

PSNR is an engineering term for the ratio between the maximum possible power of a signal and the power of corrupting noise that affects the fidelity of its representation [13]. Higher PSNR also shows better image quality.

$$PSNR(dB) = 10\log_{10}\frac{\left(2^n - 1\right)^2}{MSE} = 10\log\frac{255^2}{MSE} \quad (2)$$

3 RESULTS

Sample images contain the liver image and its noise and the noise resulted from spleen. Reference images, which contain only liver and its noise, subtracted from sample images so we obtain the noise images of spleen. Results are shown in Fig. 1 and Fig. 2. In Fig. 1 for LEGP collimator, the maximum amount of noise is seen in 5% window then in 10% window. For LEHR collimator we can also see the 5% energy window has the most noise. Some simulation results are shown in table III and IV for LEGP and LEHR collimators respectively. The information in these tables are the number of total photons that hit the crystal per second, the total counting rate and energy window counting rate of the system, scatter in energy window by order 1 and the elapse time of simulation. According to table III, smaller energy window has less counting rate in window. Elapse time for windows of 10 to 30% differ by 1 or 2 second but this time for 5% window is 11 second more than the mean of elapse time of other windows. Penetration in LEGP collimator is 1.56%. In comparison with table IV, number of hits and counting rate for LEGP are more than that for LEHR. As the window percentage increases, the scatter in window for both collimators decreases. Scatter in window for LEGP is slightly different from the same window for LEHR. Elapse time for different windows for LEHR only differ by 2 or 3 seconds. Penetration in LEHR collimator is 1.58%. The results of image quality evaluating parameters are gathered in table V. For LEGP, 20% window has the lowest MSE and the highest PSNR, and shows the best image quality. The optimum window for LEHR is 25%, which has the lowest MSE and the highest PSNR.

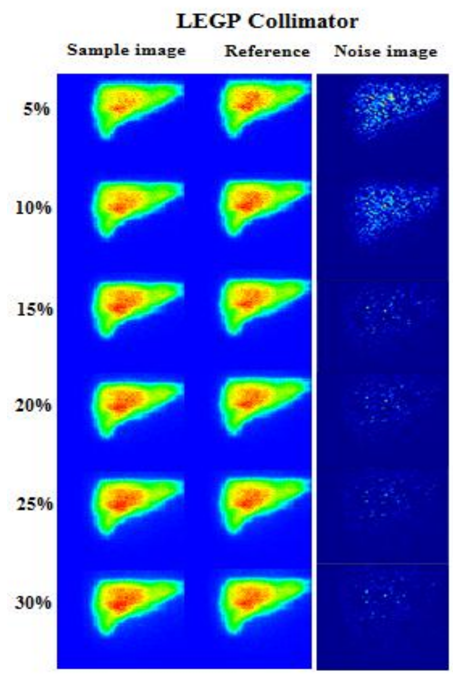

Fig1. *Sample, Reference and noise images of liver in different energy windows from 5 to 30% for LEGP collimator.*

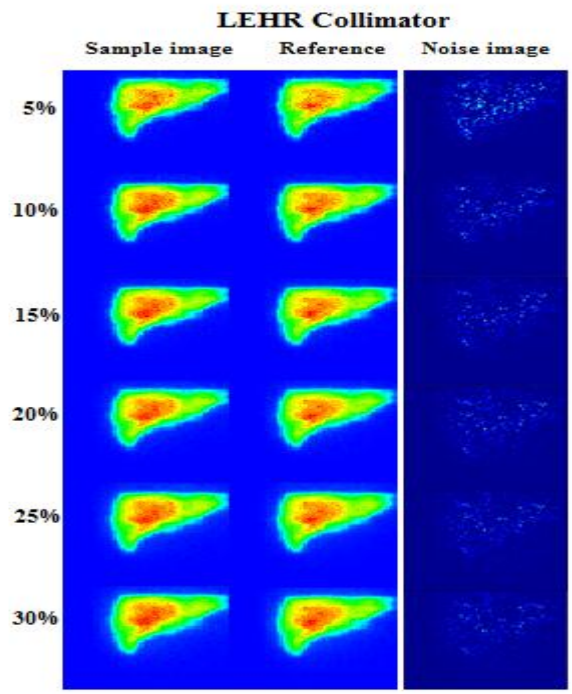

Fig. 2. *Sample, Reference and noise images of liver in different energy windows from 5 to 30% for LEHR collimator.*

TABLE III.
SIMULATION RESULTS FOR LEGP COLLIMATOR IN DIFFERENT ENERGY WINDOWS.

LEGP					
Energy window (%)	**Interaction in crystal**			**Scatter in energy window**	***Elapse time***
	Hits/sec	***Count Rate [Total]***	***Count Rate [Window]***		
5	21708.44	126.14	22.27	91.44%	5 min & 23 sec
10	21894.60	126.14	39.34	89.92%	5 min & 12 sec
15	21955.51	126.14	49.99	87.90%	5 min & 10 sec
20	21852.71	126.14	56.50	85.41%	5 min & 13 sec
25	21932.21	126.14	61.27	82.70%	5 min & 10 sec
30	21914.49	126.14	65.58	79.89%	5 min & 11 sec

TABLE IV.
SIMULATION RESULTS FOR LEHR COLLIMATOR IN DIFFERENT ENERGY WINDOWS.

LEHR					
Energy window (%)	**Interaction in crystal**			**Scatter in energy window**	***Elapse time***
	Hits/sec	***Count Rate [Total]***	***Count Rate [Window]***		
5	23159.14	77.75	13.74	91.21%	4 min & 53 sec
10	23155.41	77.75	24.24	89.85%	4 min & 53 sec
15	23276.53	77.75	30.83	87.81%	4 min & 49 sec
20	23125.64	77.75	34.84	85.37%	4 min & 53 sec
25	23246.45	77.75	37.7970	82.68%	4 min & 52 sec
30	23285.32	77.75	40.42	79.91%	4 min & 50 sec

The highest MSE and the lowest PSNR and therefore the worst image quality are acquired in 5% window for both LEGP and LEHR. When we increase energy window, at first image quality improves. MSE is decreased and PSNR is increased. But, in windows higher than 20% for LEGP and 25% for LEHR, image quality declines. MSE and PSNR for LEGP collimator in all windows are respectively more and less than that for LEHR in the same window. It shows that in the same situation, with LEHR we have better image quality.

TABLE V.
IMAGE QUALITY EVALUATING PARAMETERS FOR DIFFERENT ENERGY WINDOWS.

Energy window (%)	**MSE**		**PSNR**	
	LEGP	***LEHR***	***LEGP***	***LEHR***
5	33.87	32.68	32.83	32.99
10	23.16	23.16	34.48	34.48
15	20.55	18.86	35.00	35.38
20	18.97	16.70	35.35	35.90
25	20.09	16.44	35.10	35.97
30	20.76	17.43	34.96	35.72

5 CONCLUSION

In higher windows, more photons hit crystal so counting rate in higher windows is more. Therefore, we have more data. However, these additional data can be because of the noise that superimposed on liver image. We did not include statistical noise in our simulation. The image of liver and its noise is subtracted in each window so we purely have structured noise from spleen. We should decrease the window to decrease this noise. As shown in Fig. 1 and 2 and according to table V, decreasing energy window more than an optimum percentage can also increase the noise. It can be because of acquisition time. In 5% window, elapse time for LEGP is more than other windows. But, in LEHR elapse time of different windows are not much different from each other. Scatter in energy window can be the other factor that causes the increment of noise in small energy windows. The most scatter in window, for both LEGP and LEHR is in 5% window, and by increasing the energy window, it is decreased. Higher energy windows cause more photons with lower energy less than 140kev be recorded and it increases the noise. Penetration in LEGP is less than that in LEHR, because thickness of LEGP is more than that of LEHR. However, hole size of LEGP is bigger so more photons can hit crystal of gamma camera, and more counting rate both in total and in window are obtained for LEGP. This increases the noise too. As we can see, type of collimator effect the amount of noise and the optimum energy window. 20% window is the optimum window for LEGP while 25% window is appropriate for LEHR. However, for LEHR, the result of MSE and PSNR in 20% and 25% are not much different. Therefore, 20% window can be used for LEHR too.

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