Assessment of the Contrast to Noise Ratio in PET Scanners with Monte Carlo Methods

C. M. Michail[1], G. E. Karpetas[2], G. P. Fountos[1], I. G. Valais[1], D. Nikolopoulos[3], I. S. Kandarakis[1] and G. S. Panayiotakis[2]

[1]Radiation Physics, Materials Technology and Biomedical Imaging Laboratory, Department of Biomedical Engineering, Technological Educational Institute of Athens, Egaleo, 122 10 Athens, Greece

[2] Department of Medical Physics, Faculty of Medicine, University of Patras, 265 00 Patras, Greece

[3] Department of Computer Electronic Engineering, Technological Education Institute of Piraeus, Greece, Petrou Ralli & Thivon 250, 122 44, Aigaleo, Athens, Greece

e-mail: gfoun@teiath.gr

Abstract. The aim of the present study was to assess the contrast to noise ratio (CNR) of PET scanners through a thin layer chromatography (TLC) plane source. The source was simulated using a previously validated Monte Carlo model. The model was developed by using the GATE MC package and reconstructed images obtained with the STIR software for tomographic image reconstruction. The PET scanner simulated was the GE DiscoveryST. A plane source consisted of a TLC plate, was simulated by a layer of silica gel on aluminum (Al) foil substrates, immersed in 18F-FDG bath solution. Image quality was assessed in terms of the CNR. CNR was estimated from coronal reconstructed images of the plane source. Images were reconstructed by the maximum likelihood estimation (MLE)-OSMAPOSL. OSMAPOSL reconstruction was assessed by using various subsets (3, 15 and 21) and various iterations (2 to 20). CNR values were found to decrease when both iterations and subsets increase. Two (2) iterations were found to be optimal. The simulated PET evaluation method, based on the TLC plane source, can be useful in image quality assessment of PET scanners.

Keywords: PET; CNR; image quality; Monte Carlo

1. Introduction

In positron emission tomography (PET) scanners, iterative reconstruction, based on maximum likelihoods such as the ordered subset expectation maximization (OSEM) algorithm, has been widely adopted for clinical practice [1]. However, in OSEM, resolution and noise cannot be assessed in a straight manner, such as in filtered backprojection reconstructed images, since iterative reconstruction algorithms are non-linear and difficult to evaluate [2]. The major consideration, when using iterative reconstruction algorithms, is to retain noise and processing time into acceptable levels. To this aim, the number of iterations should be carefully selected in order to compromise between resolution and noise-processing time [3]. In clinical practice, where the number of iterations is limited due to time restrictions, resolution may differ in different objects within an image, depending on their relative size and intensity [2]. The number of iterations affects both the resolution and intensity of PET in the following manner. By increasing the number of iterations, within a reasonably wide range of practically encountered clinical situations [1], resolution improves and tumors appear brighter. However, this behavior reaches to a point that thereafter resolution cannot be further improved [4,5]. The aim of this study was to assess both resolution and noise, in terms of the contrast to noise ratio (CNR) [6,7]. Increased CNR values preserve spatial resolution, while retaining noise into acceptable levels and in a

clinical context, could allow better detection and earlier diagnosis [6]. To this aim coronal images of a flood source were obtained [8] following the work of Fountos *et al*. [9,10] for SPECT scanners resolution assessment. A previously validated Monte Carlo model [11,12] was used in order to obtain the PET images, by using different number of iterations and subsets in the iterative image reconstruction. Within the context of the model, CNR was estimated by the simulation of a thin layer chromatography (TLC) plane source filled with 18F-FDG using a software model based on the GATE Monte Carlo package. The GATE package is an open-source extension of the Geant4 Monte Carlo toolkit [13]. GATE was used in combination with the STIR image reconstruction software [14] to obtain the plane source reconstructed images. The simulation of this plane source phantom provides an accurate model that is useful to fully characterize the performance of nuclear medicine imaging systems.

2. Materials And Methods

1.1 Geometry of the modeled PET scanner

In this study the Discovery ST PET/CT system was modeled. The system incorporates bismuth germinate oxide (BGO) [15,16] crystals with dimensions of 6.3x6.3x30 mm^3 in the tangential, axial and radial directions, respectively. The detector ring is finally comprised of 35 modules, i.e. 280 crystal blocks, or 24 rings of 420 crystals (for a total of 10080 BGO crystals). The dimensions of the rings are 88.6 cm diameter with a 15.7 cm axial and 70cm transaxial fields of view (FOV).

2.2. Software for simulation

The simulation software, employed in the present study, was built around the GATE toolkit, which in turn is based on the Geant4 platform. In every BGO crystal, of the detector block, a Gaussian energy blur is applied with an average energy resolution of 17%, referenced at 511 keV. Afterwards, a 300 ns dead time value was applied on the single events in the BGO crystal [17] by a paralysable Deadtime module. The Quantum Detection Efficiency (QDE) [18,19] of the crystals was found 0.94 at 511 keV. The sinogram output file (.ima) was used by STIR as input file for the reconstruction of the simulated plane source image. The coincidence time window was set to 11.7 ns.

2.3. Preparation of the phantom

The phantom was a planar source similar to those used in previous works of Boone [20] for CT and Fountos *et al*. [9,10] for SPECT systems. The idea for the particular 18F-FDG plane source was based on the excellent binding of 18F-FDG with TLC plates [8]. The plate was considered to consist of a layer of silica gel on Al foil substrates (Al density 2.7 g/cm^3). The dimensions of the TLC plate were 5x10 cm^2 and it was assumed to be immersed in an 18F-FDG bath solution (1 MBq). The plane source (i.e. the radioactive plate) was simulated between two semi-cylindrical polyethylene blocks with 20 cm diameter and 70 cm length, in the horizontal and vertical direction.

2.4 Contrast to Noise Ratio (CNR)

CNR was obtained, by using equation (1) [6,7].

$$CNR = \frac{\overline{\mu_2} - \overline{\mu_1}}{\sqrt{SD_1{}^2 + SD_2{}^2}} \quad (1)$$

Where μ_1 and μ_2 are the mean pixel values, calculated from regions of interest (ROIs) within hot (in the source) and cold (out of the source) areas respectively. SD_1, SD_2 are the corresponding standard deviation (SD) values.

3. Results and Discussion

3.2 Contrast to Noise Ratio (CNR)

Figure 1 shows the resulted CNR values when the number of iterations and subsets are allowed to vary, in order to investigate the impact on PET image quality. The examined combinations of iterations and subsets are:3 subsets with 2, 6,8,14 and 20 iterations, 15 subsets with 4, 6,12,14 and 20 iterations, and 21 subsets with 2, 6,10,14 and 20 iterations. As it can be seen, CNR values decrease when the number of iterations and subsets increase. When the number of iterations increases, contrast also improves, but with a corresponding increase in image noise. However the increase in image noise is of greater dimensions, compared with resolution improvement, leading to a decrease of the CNR values. Optimal CNR was obtained for 2 iterations [6] and 3 subsets.

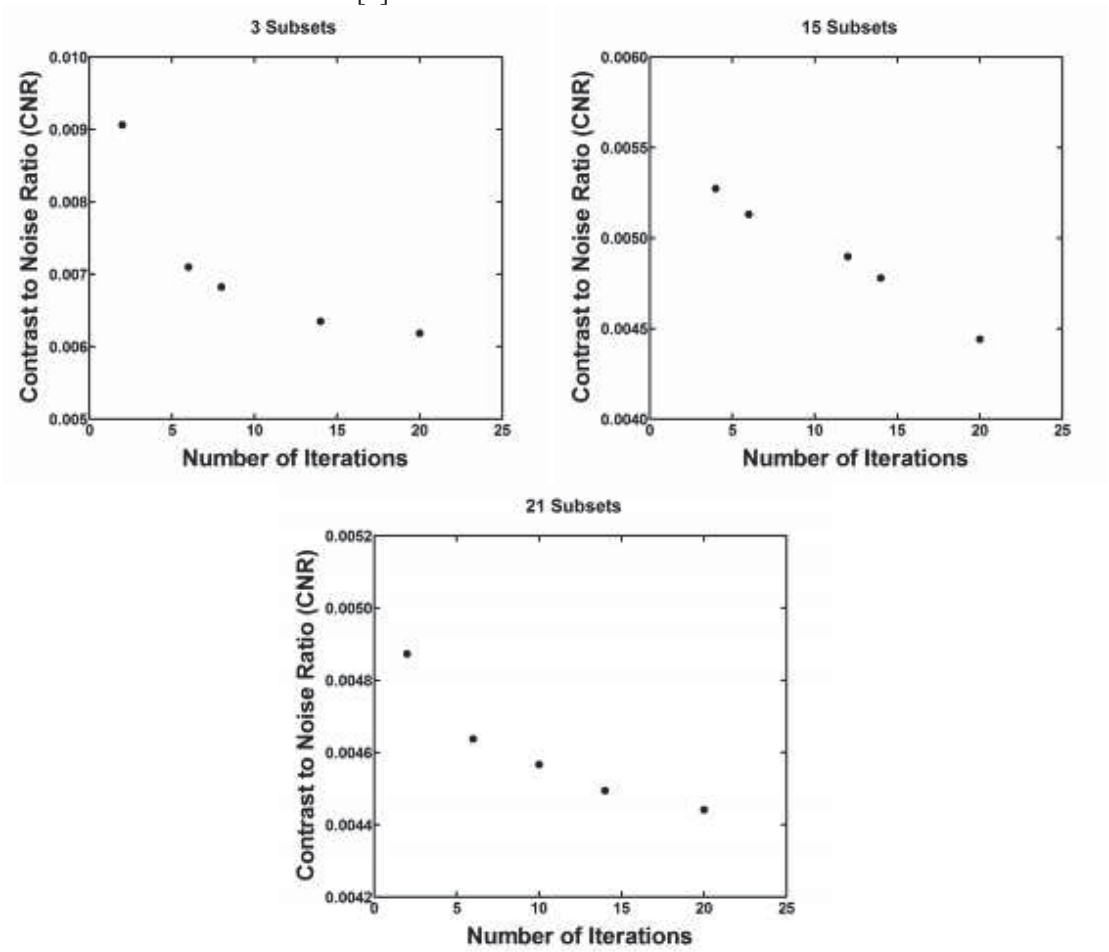

Figure 1. CNR values obtained from the OSMAPOSL reconstructed images using various iterations and subsets a) 3 subsets, 2, 6,8,14 and 20 iterations, b) 15 subsets, 4, 6,12,14 and 20 iterations, c) 21 subsets, 2, 6,10,14 and 20 iterations.

4. Conclusions

Image quality characterisation of a PET scanner was achieved through the estimation of the CNR of thin 18F-FDG plane source reconstructed images, simulated by a Monte Carlo model. The influence of iterative image reconstruction on the plane source simulated images was investigated by using various

subsets and iterations. CNR values were found to decrease by increasing the number of iterations (number of image updates) and subsets. The method was used for the image quality assessment and optimisation, but it can be also useful in research for the further development of PET and SPECT scanners though GATE simulations.

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5. References

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