Medical Imaging Image Quality Assessment with Monte Carlo Methods

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Abstract. The aim of the present study was to assess image quality 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, with cluster computing. The PET scanner simulated in this study 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 (1MBq). Image quality was assessed in terms of the Modulation Transfer Function (MTF). MTF curves were estimated from transverse reconstructed images of the plane source. Images were reconstructed by the maximum likelihood estimation (MLE)-OSMAPOSL algorithm. OSMAPOSL reconstruction was assessed by using various subsets (3 to 21) and iterations (1 to 20), as well as by using various beta (hyper) parameter values. MTF values were found to increase up to the 12th iteration whereas remain almost constant thereafter. MTF improves by using lower beta values. The simulated PET evaluation method based on the TLC plane source can be also useful in research for the further development of PET and SPECT scanners though GATE simulations.

Keywords: PET; MTF; image quality; iterative reconstruction; Monte Carlo; GATE; STIR

1. Introduction

The most common image quality metrics in order to assess spatial resolution in Positron Emission Tomography (PET) scanners are the Point Spread Function (PSF) and the corresponding Full Width at Half Maximum (FWHM) obtained from point sources [1]. Only in a few studies spatial resolution was assessed in terms of the Modulation Transfer Function (MTF), calculated from PSF data [2]. The same method was employed in studies concerning combined micro PET/CT scanners, in which MTF was estimated in the CT detector of the combined system [3,4]. MTF can be also assessed from a line source through the estimation of the line spread function (LSF). The use of the LSF method for determining the MTF in tomographic imagers was initially introduced by Boone [5] who applied this method for CT scanners evaluation. Fountos *et al*. [6,7] recently introduced a similar method for SPECT scanners by immersing an Agfa MammoRay HDR Medical X-ray film in a solution of dithiothreitol (DTT)/Tc-99m(III)-DMSA to obtain the MTF through the LSF method. The purpose of the present study was to extend a previous validated Monte Carlo model [8-10] in order to obtain PET image resolution through the estimation of the MTF. The model could be useful in implementing experimental methods for systems evaluation in clinical practice as well as in research for further improvement of the image quality performance in PET scanners. Within the context of the model, MTF 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, which was developed by the Open-GATE collaboration, is an open-source extension of the Geant4 Monte Carlo toolkit [11]. GATE was used in combination with the STIR image reconstruction software [12] to obtain the plane source reconstructed images. The influence of different number of iterations (corresponding to a complete cycle) with various subsets in the iterative image reconstruction was also investigated. 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

2.1 Geometry of the modeled PET scanner

In this study the Discovery ST PET/CT system was modeled. The system incorporates bismuth germinate oxide (BGO) [13] crystals with dimensions of 6.3x6.3x30 mm 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 [14] by a paralysable Deadtime module. The Quantum Detection Efficiency (QDE) [15,16] 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 MTF test object

The MTF test object, which was simulated in this study, was a planar source similar to those used in previous works of Boone [5] for CT and Fountos *et al*. [6,7] for SPECT systems. The idea for the particular 18F-FDG plane source was based on the excellent binding of 18F-FDG with TLC plates [10]. 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 MTF test object (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. The importance of the hyper parameter (beta value) (which controls the weight of the penalty term and the importance of the prior) was also examined in order to investigate the corresponding influence on the MTF [17].

2.4. Modulation Transfer Function (MTF)

MTF was obtained, by using the LSF method. In this method, the thin plane source was simulated at a slight angle of 3^o with respect to the horizontal or vertical axis, following the technique proposed by Fujita to avoid aliasing effects [18]. The final LSF was obtained by averaging all line LSF profiles after angle correction. The angle correction was performed following the procedure described in Fountos *et al*. [6].

3. Results and | Discussion

3.1. Iterative Image Reconstruction

Figure 1a shows transverse image slices, used for the MTF calculation through the LSF method [6], of the plane source reconstructed with the OSMAPOSL algorithm with subsets ranging from 3 to 21 and iterations from 2 to 20. Figure 1b shows transverse plane source reconstructed images with the OSMAPOSL using 2, 5 and 20 iterations with fixed subsets (15) using various values of the beta (hyper) parameter (0.01, 1 and 3). These data were obtained in order to investigate the influence of the beta parameter on image resolution.

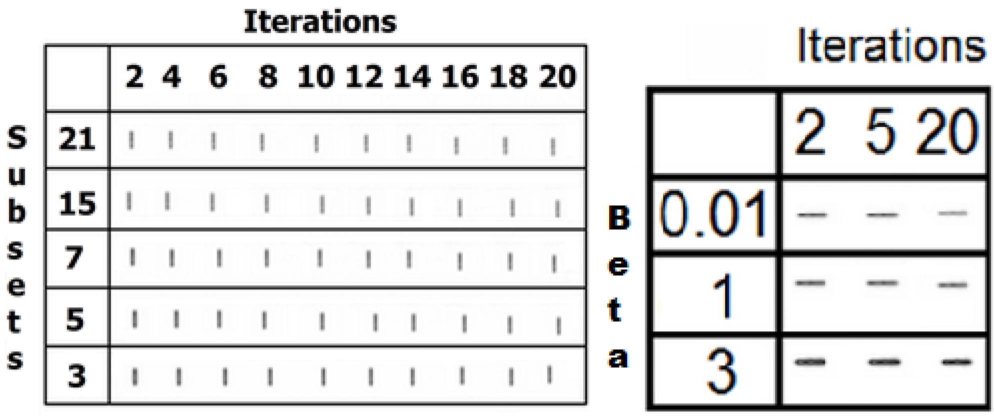

Figure 1. Transverse slices, from the plane source reconstructed images with the OSMAPOSL a) (3, 5, 7 and 21 subsets, various iterations) and b) (15 subsets, 2, 5 and 20 iterations) using various values of the beta (hyper) parameter.

3.2. Modulation Transfer Function (MTF)

Figure 2 shows MTF curves obtained from iterative STIR reconstructed LSF images. The curves correspond to transverse reconstructed slices in which the number of subsets was kept fixed and the number of iterations was increased with a step of 2. In every case MTF was found to increase up to 10 iterations and remain almost stable thereafter. However, the range of this increase in the MTF is limited as the number of subsets increases. In Fig.2 (3 subsets) the MTF values at 0.04 cycles/mm range from 0.208 (2 iterations) to 0.507 (20 iterations). MTF reaches a plateau at a value of 0.492 (12 iterations). With 21 subsets, the MTF values at 0.04 cycles/mm range from 0.432 (2 iterations) to 0.495 (20 iterations). The MTF value where the increase stops is 0.489 (12 iterations). Furthermore in figure 2 the influence of the number of subsets on the reconstructed image is shown. In order to obtain these values, the number of iterations was kept constant (2 and 10 iterations) and the number of subsets was allowed to vary from 3 to 21. The obtained MTF values show that as the number of iterations increases, the impact on image resolution is restricted.

Figure 3 shows the resulted MTF curves when the hyper parameter is allowed to vary from a value close to zero up to 3, in order to investigate its impact on PET image resolution through the MTF. As it can be seen, spatial resolution is improved by using lower beta values [17]. Larger beta values result in smoother images, while lower values decrease the importance of the penalty term [17,19]. By increasing the number of iterations, the influence of the beta parameter on image resolution tends to decrease showing smaller deviations. For example, in the 15 subsets/2 iterations image, deviations of the order of 60.2% are shown between the 0.01 and 3 beta value, whereas in the 15 subsets and 20 iterations image the corresponding difference decrease to 31.3%, at the spatial frequency of 0.05 cycles/mm.

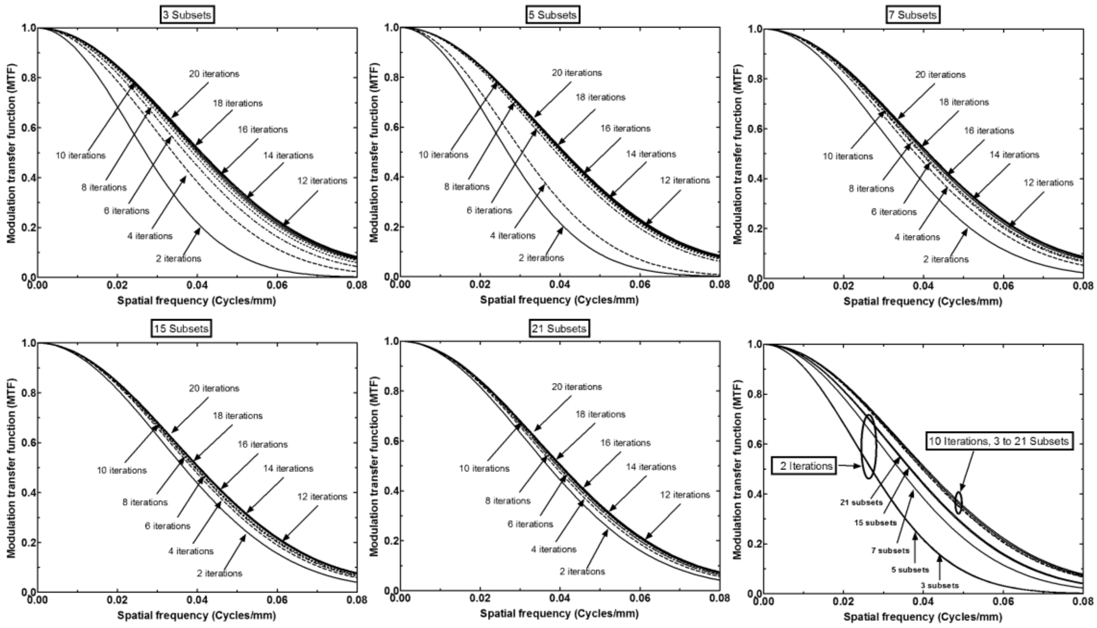

Figure 2. Comparison between the MTFs obtained with the LSF method, from the plane source reconstructed image with the OSMAPOSL (3 to 21 subsets, various iterations and various subsets, 2 and 10 iterations).

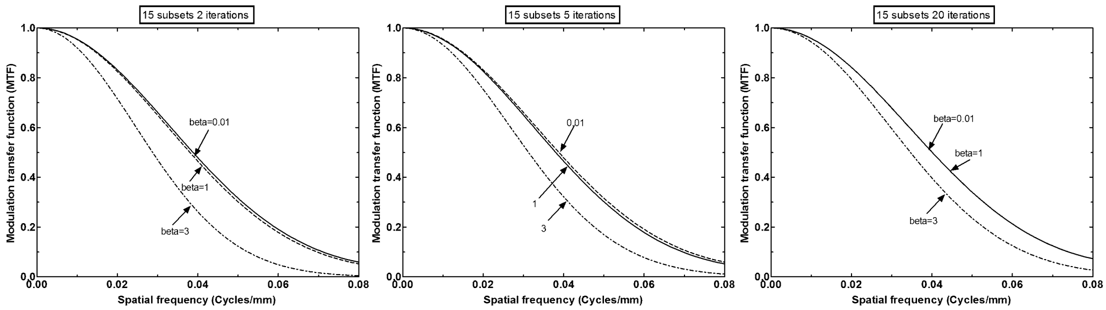

Figure 3. Comparison between the MTFs obtained from the OSMAPOSL (15 subsets, 2, 5 and 20 iterations) reconstructed images using various values of the beta (hyper) parameter.

4. Conclusions

Image quality characterisation of a PET scanner was achieved through the estimation of the MTF 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 (3 to 21) and iterations (1 to 20). Image quality was found to improve by increasing the number of iterations (number of image updates) (up to 12). Spatial resolution is also improved by using lower beta values. Larger beta values have as a result smoother images, while lower values decreases the importance of the penalty term. 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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STIR is the successor of the PARAPET software library which was the result of a (European Union funded) collaboration between 6 different partners http://stir.sourceforge.net.

5. References

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