

The use of Modulation Transfer Function as an Overall Quality Control parameter in PET/CT

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Abstract. *The Modulation Transfer Function (MTF) is an important parameter for the characterization of image quality and the signal transfer properties of an imaging system. To develop a new method for MTF determination of PET/CT in three dimensions (3D), a novel and highly uniform, film based flood source using 18F-FDG has been prepared. The source was placed between PMMA blocks of various thicknesses, and imaged in a GE Discovery-ST, PET/CT system. MTF was then calculated from the line spread function (LSF) profile of the film. The film was prepared by immersing silica gel matrix, Al foils (5×10cm Fluka) in 18F-FDG bath solution. The effects of different reconstruction algorithms and the shape of the scanned object on MTF were investigated. By this method the alignment of PET and CT in the fused image was investigated as well. Hence the MTF can be used as an overall quality control parameter in PET/CT.*

Keywords: PET/CT, Line Spread Function (LSF), Modulation Transfer Function (MTF), reconstruction algorithms, quality control.

1 INTRODUCTION

Many attempts have been made to characterize tomographic imaging systems by combining factors that describe each component into one figure of merit. The signal spread of an imaging system can be described by the point spread function (PSF) or the Line Spread Function (LSF). The full width at half maximum (FWHM) of these functions is the most used measure of the resolution of a system^{[1]-[9]}. An alternative is to use the Modulation Transfer Function (MTF) in order to describe the ability of the system to maintain the amplitudes of spatial frequencies passing through it.

The objectives of this work were a) to prepare a film-based flood source, (i.e. a thin film with uniform distribution of a radioisotope) with a fast and low cost method,

based on materials easily accessible at the hospital, b) to develop a new method for the Modulation Transfer Function (MTF) determination of a hybrid PET/CT system in three dimensions (3D) and c) to explore the possibility of using MTF as an overall quality control parameter in PET/CT. The key to this approach was the preparation of a novel and highly homogeneous - high activity film flood source, based on F-18 as the positrons emitting nuclide and subsequently the two gamma 511 keV photons.

2 MATERIALS AND METHODS

2.1 Preparation of a film-based flood source

To prepare the highly homogeneous flood source, chromatography paper on Al foil (5×10 cm Fluka film) and chromatography paper on plastic base were used.

The Fluka films were incubated with Fluorodeoxyglucose (18F-FDG). In all incubation experiments, the films were thoroughly immersed in a standardized volume (100 mL) of water for injection containing the radiopharmaceutical solution and they were incubated for a specified time period of 5 minutes. In the case of the chromatography paper on plastic base a cup of oral opaque was added into the radiopharmaceutical. At the end of incubation, the films were dry-blotted and left to dry for 5 minutes. Subsequently they were placed between poly methyl-methacrylate (PMMA) blocks of various thicknesses and imaged in a General Electric Discovery ST, PET/CT scanner. Coronal images of the films (matrix: 256x256) were carefully re-viewed for in-homogeneities in the radioactivity distribution. The film / radiopharmaceutical combination exhibiting the best homogeneity was obtained by using chromatography paper on plastic base incubated for 5 minutes with the 18F-FDG radiopharmaceutical solution and oral opaque.

These films (5×10cm Fluka) were placed tightly between 2 and 8 cm of PMMA blocks in vertical and horizontal position.

The head phantom with the film food source, placed between PMMA blocks, is shown in Figure 1.a .

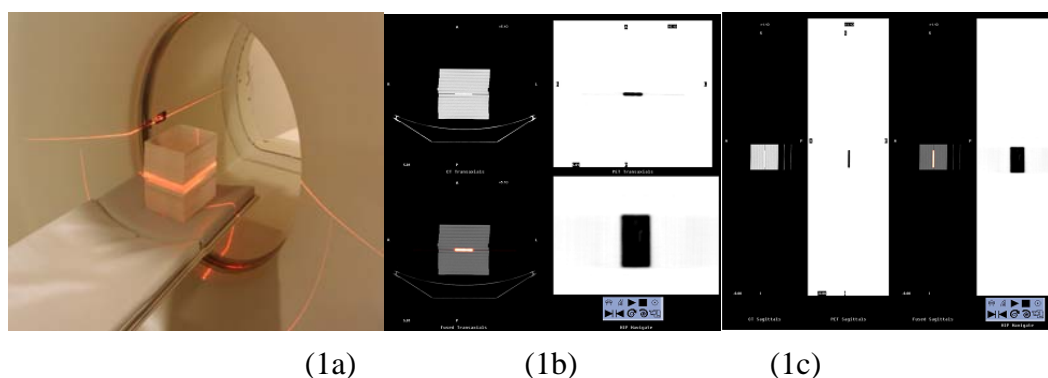


Figure 1 1a) the head phantom source consisted of PMMA blocks with the film flood source inside,
1b) transaxials and 1c) sagittal slices of the phantom with the film flood source in horizontal position.

The phantom was imaged using the whole body (WB) 2D PET/CT and the HEAD 3D PET/CT standard imaging protocols in a GE Discovery ST hybrid PET/CT scanner. The reconstructed transaxials and the sagittal slices of the phantom placed almost

horizontally, are shown in figure 1.b and 1.c respectively, where the CT, the attenuation corrected PET and the fused images are also presented.

2.2 MTF calculation

The MTF curves were calculated with the LSF method. Fourier transformation and subsequent normalization procedures are then applied to the LSF to compute the MTF [6], [7], [8].

Gray level profiles from the CT and PET images, were obtained in directions almost vertical (20) to the imaged lines. These profiles were then averaged to obtain the LSF and afterwards fitted with a Gaussian filter.

The reconstruction methods for the PET 3D brain protocol were the following: Filtered Back Projection (FBP) with Hanning, RAMP, Shepp-Logan, Butterworth and Enchanted Hanning filters, as well as Iterative 3D reconstruction with 5 and 10 iterations. In all algorithms the technique of Fourier rebinning (FORE) has been applied to convert the 3D collected data onto a set of parallel sinograms so they could be reconstructed using the conventional 2D filtered back projection methods.

The effects of filtering, image reconstruction method and the shape of the scanned object on MTF, were investigated as well.

3 RESULTS AND DISCUSSION

Representative imaging results of the film / radiopharmaceutical incubation experiments are shown in Figure 2.

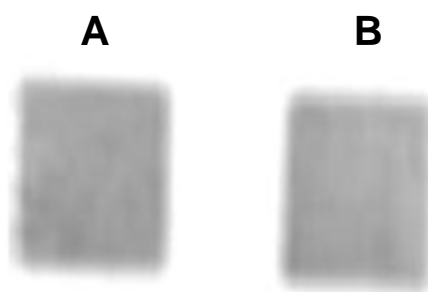


Figure 2: Representative examples of ¹⁸F-FDG distribution on chromatography paper with Al (A) and plastic base (B).

Homogeneity of ¹⁸F-FDG radioactivity distribution and uptake of the radiopharmaceutical onto the films were adequate for imaging purposes (uniformity < 2%, count rate 5 to 15 kcps during PET acquisitions). Although in our experiments, careful handling was imperative by avoiding touching the paper surfaces with bare fingers. In figure 3 the low dose CT image of the chromatography paper with Al base and its line spread function are presented.

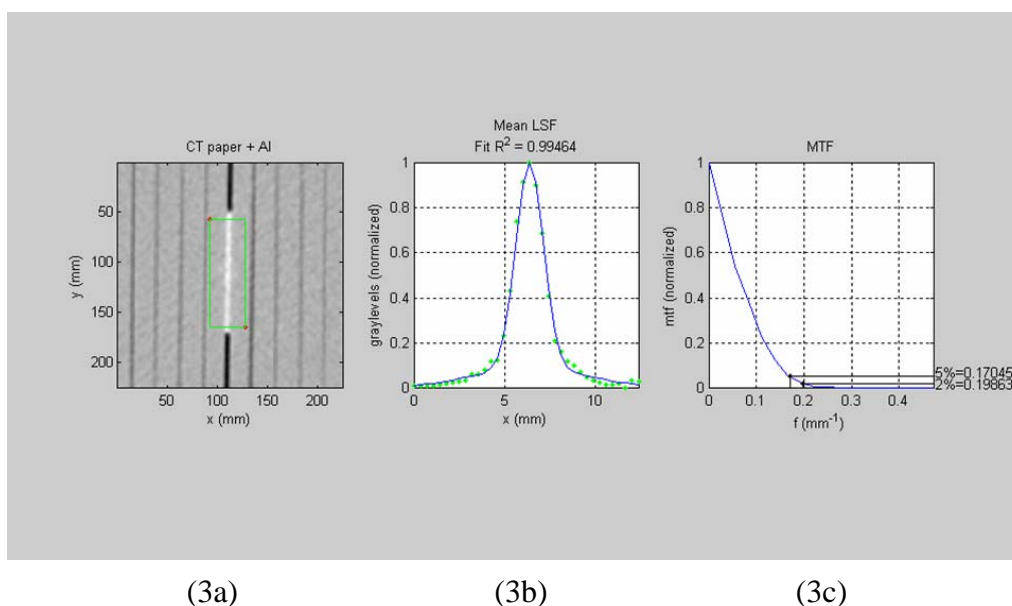


Figure 3: 3a the low dose CT image of the chromatography paper with Al base 3b) LSF and 3c) MTF with the values that correspond at 2 and 5 percent level.

The Gaussian fitting for the LSF gave a $R^2=0.995$, which is very close to unity. The third graph, in figure 3, is the Modulation Transfer Function for standard kernel and number's correspond to its 2 and 5 percent level.

In figure 4 the PET images of the previous film with the phantom scanned in 2D PET mode with septa extended (figure 4.up) and in 3D PET acquisition with the septa retracted (figure 4.bottom) are presented.

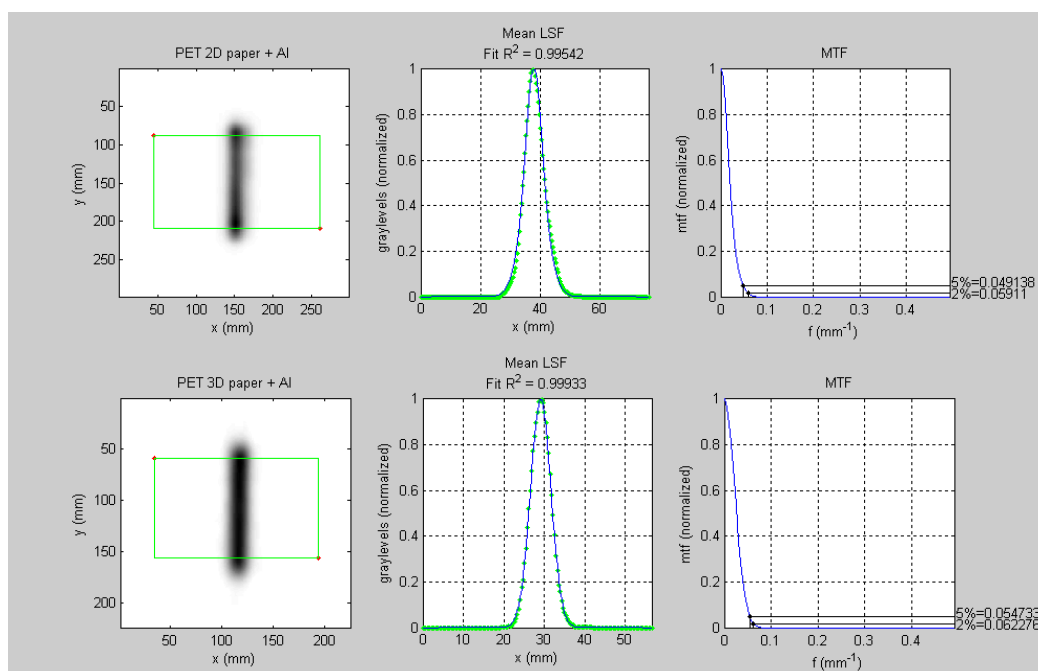


Figure 4: PET image of the chromatography paper with Al base scanned in 4 up) 2D mode and 4 bottom) 3D mode with their corresponding line spread functions and modulation transfer functions.

The values of the R^2 , for the Gaussian fitting in LSF, were also close to unity.

In figure 5 calculated results for the Modulation Transfer Function, obtained from the PET 3D brain protocol are shown for different reconstruction algorithms / filters. The transaxial slice of the source in horizontal position was used for the MTF determination.

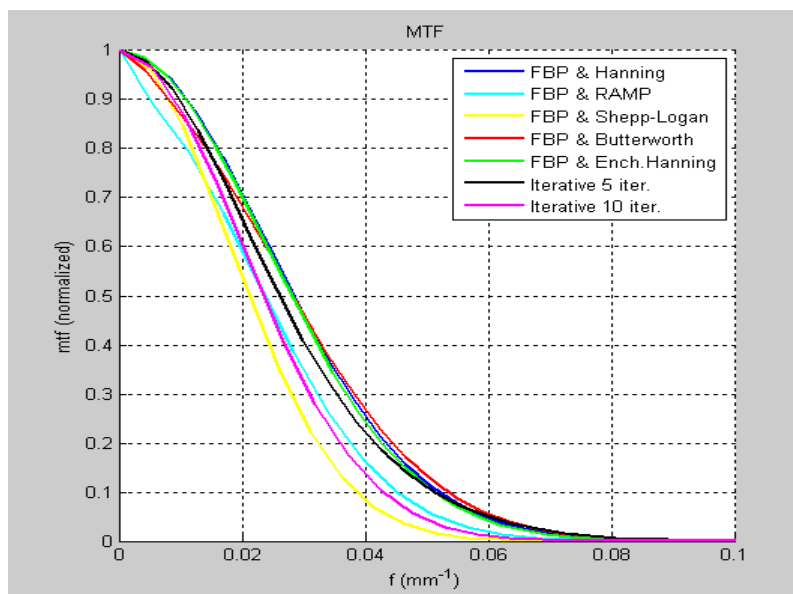


Figure 5: Modulation Transfer Function of images reconstructed with different algorithms/filters.

The iterative reconstructions are better than the Filtered Back Projection. High MTF values in the low frequency range is needed to outline the coarse details of the image and is important for presentation and detection of relatively large but low contrast lesions. Consequently increased MTF values in the high frequency range are necessary to portray fine details and sharp edges. This is of obvious importance for small objects but also sometimes for larger objects because of the importance of edges and sharp borders for detection of low contrast objects and for accurate assessment of their size and shape.

By using the PET 3D brain protocol and FORE filtered back projection with Hanning filter, we computed the MTFs for the plexiglas widths of 4 and 16 cm, from the transaxial slice of the source in horizontal position (figure 6).

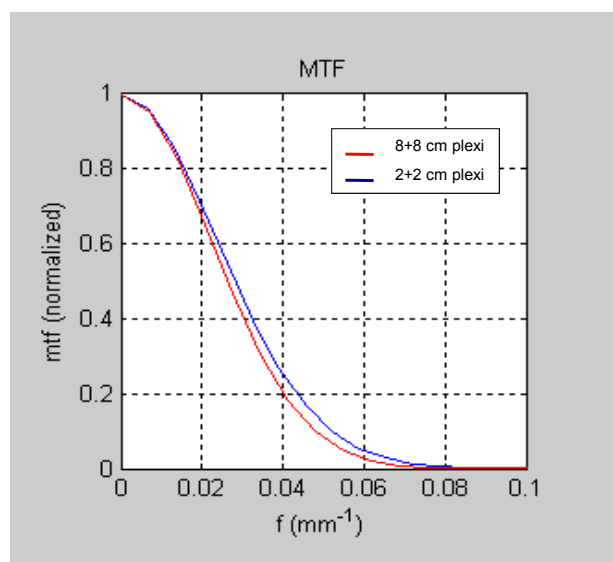


Figure 6: The effect of different plexiglas widths on Modulation Transfer Function.

While low frequency response is similar there are differences in the high frequency area, as the plexiglas block thickness increases.

In addition by the method proposed, the shift between the CT and the PET images in fusion can be calculated in both axes. This is possible by scanning the two channels of the fused image, (grey which represents the CT data and red which represents the PET data). By plotting the corresponding Line Spread Functions in the same graph the shift between the CT and the PET image in fusion can be evaluated (figure 7).

The shift in our case was about one pixel which represented a sub-millimetre value of misregistration. This kind of accuracy in the displacement of the two images is far better from the method proposed by the manufacturer for the scanner. Manufacturer's method has a limit of 2 mm which also is the limit for the scanner.

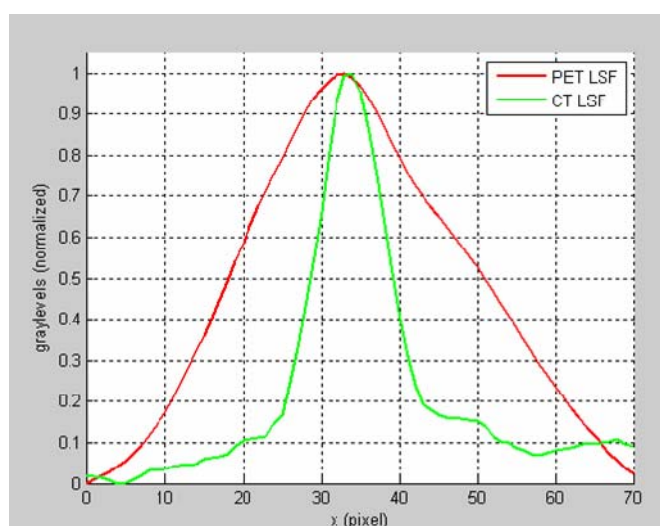


Figure 7: Registration shift between the CT and the PET image in fusion.

Similar results were observed for the saggital slice, when the phantom was placed horizontally and for the transverse and coronal slices, when the phantom was placed vertically.

Our results are comparable with the results from previous work done for the determination of the MTF in computed tomography ^{[6][11]}.

The availability, to the medical physicist, of CT and PET images in digital format images leads to the opportunity to perform more quantitative measurements of system performance. The determination of the MTF, as described here, capitalizes on this opportunity.

The LSF synthesis method employed here uses about 25 times more data than conventional PSF-integration techniques, because a line of data is used instead of a point, and so this technique should be less prone to noise due to the benefits of averaging over larger samples. This may be the principal benefit of the proposed technique in the context of clinical CT and PET MTF measurements. In addition, the technique is less prone to aliasing than the PSF integration technique because of the finer effective pitch used to synthesize LSF. It is worth noting that aliasing does not simply “turn on” at the Nyquist frequency, there is in fact a gradual albeit subtle increase in aliasing as the Nyquist frequency is approached—this is evidenced in MTFs which begin to bow upwards as the Nyquist frequency is approached. ^[12]

The proposed MTF technique uses a simple phantom that can be assembled from inexpensive materials readily available to the medical physicist, just some chromatography paper on aluminium foil and several flat slabs of Lucite. This fact, combined with the computational simplicity and resiliency to noise, suggests that the calculation of the MTF may be an excellent alternative to the conventional PSF integration technique.

Although further evaluation of our method is required, it provides an easy means to evaluate the frequency response of each kernel available. Our experiments showed that MTF measurements are well suited for routine clinical applications as part of a quality control program, where reproducibility is especially important.

4 CONCLUSIONS

The method presented is novel and easy to implement for characterization of the signal transfer properties and image quality of PET/CT systems. It requires cheap and easily accessible materials, available to the medical physicist in the Hospital.

Furthermore, is robust to aliasing and since this technique is based on the LSF method, is more resilient to noise due to greater data averaging than conventional Point Spread Function (PSF)-integration techniques.

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