Assessment of Image Quality in SPECT Systems via the implementation of a novel flood source technique

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Abstract. *The Modulation Transfer Function (MTF) is an important parameter for the characterization of the signal transfer properties and image quality of a single photon emission computed tomography (SPECT) system. MTF can be derived by determining the line spread function (LSF) from images of a flood source. The method presented here is novel and easy to implement, requires materials commonly found in clinical practice, is robust to aliasing. Furthermore, since this technique is based on the LSF method, reduces measurement noise levels due to greater data averaging than conventional Point Spread Function (PSF)-integration techniques. In an effort to prepare easily, cheaply and reproducibly a Tc-99m-based flood source (E_γ=140 keV), various combinations of films and radiopharmaceuticals were tried. Excellent results were obtained by immersing an Agfa MammoRay HDR Medical X-ray film in a solution of dithiothreitol (DTT, 10^{-3} M)/Tc-99m(III)-DMSA (DMSA:Trivalent Technetium-99m-dimercapto-succinic acid, 40 mCi/40 mL) for 30-45 min in the dark. These films exhibited high integral uniformity (CV <1.9%). All imaging experiments were performed in a Siemens e-Cam γ-camera.*

Keywords: SPECT, ^{99m}Tc(III)-DMSA, MTF, LSF, film, flood source.

1 INTRODUCTION

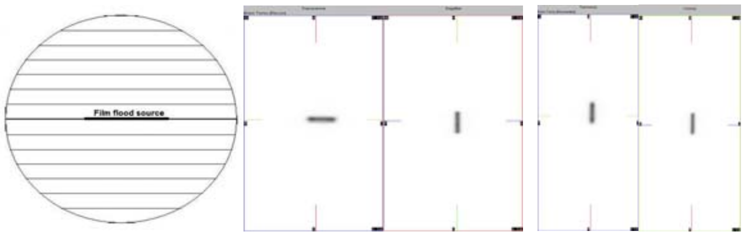
The Modulation Transfer Function (MTF) can be used to characterize the signal transfer properties of a single photon emission computed tomography (SPECT) scanners in the spatial frequency domain [1]. In tomographic imaging systems several methods to measure LSF, PSF and MTF have been reported [2]–[9]. The MTF of a SPECT imaging system can be obtained by determining the line spread function (LSF) from images of a flood source. The objective of this work was primary 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, using materials easily found and accessible in clinical practise, in the Nuclear Medicine Department, and secondary to estimate the MTF of SPECT systems using the LSF method, in order to exploit the advantages of LSF over PSF. The *sine qua non* of this approach was the preparation of a highly homogeneous and high activity film-based flood source, using Tc-99m as the γ-radiation emitting nuclide (E_γ=140 keV).

2 MATERIALS AND METHODS

2.1 Preparation of a film-based flood source

To prepare the highly homogeneous flood source the following film substrates were selected: the LR 115-type 2 (Kodak-Pathe, France), the Agfa Drystar TS 2C (Agfa-Gevaert, Mortsl, Belgium), the Agfa MammoRay HDR Medical X-ray film (Agfa-Gevaert, Mortsl, Belgium) and the inkjet transparency film OHP Ref: KF01146 (Interaction-Connect, Gent, Belgium). The radiopharmaceutical solutions, used for the radioisotope distribution within the films, were the following: Tc-99m(III)-DMSA (Technescan® DMSA, Mallinckrodt BV, Petten, Holland), Tc-99m methylene diphosphonate (Amerscan Medronate II, GE Healthcare Limited, Buckinghamshire, UK) and Tc-99m-tetrofosmin (Myoview®, GE Healthcare Limited, Buckinghamshire, UK). All solutions were prepared according to the package insert instructions. The eluate of the Elumatic® III Tc-99m Generator (CIS bio international, Gif Sur Yvette, France) was used as the $Na^{99m}TcO_4$ source. The photographic films were incubated with the radiopharmaceutical solution either under normal laboratory illumination conditions (exposed) or in the dark (unexposed). In all incubation experiments, the films were thoroughly immersed in a standardized volume (40 mL) of water for injection containing the radiopharmaceutical solution. The films were incubated for specified time periods, ranging from 2 min to 45 min. A separate incubation experiment was carried out with the addition of an appropriate amount of reagent-grade dithiothreitol (DTT, Sigma-Aldrich, St Louis MO, USA) in the Tc-99m(III)-DMSA solution (final concentration in DTT: 10^{-3} M). At the end of the incubation, the films were rinsed with water for injection and dry-blotted. They were then placed between methyl-methacrylate blocks of various thicknesses and imaged in a Siemens e-Cam γ-camera (Erlangen, Germany). The obtained 500 kcounts planar images of the films (matrix: 256x256) were carefully reviewed for in-homogeneities in the radioactivity distribution. The film /radiopharmaceutical combination exhibiting the best homogeneity was obtained using the DTT-stabilized Tc-99m(III)-DMSA radiopharmaceutical solution and the Agfa MammoRay HDR Medical X-ray film (unexposed). This combination was then imaged using the DatScan® and Tc-99m-MIBI scan protocols of the Siemens e-Cam γ-camera.

The Tc-99m(III)-DMSA/Agfa MammoRay HDR Medical X-ray film used in brain and heart SPECT imaging protocols (DatScan® and Tc-99m-MIBI, MIBI: methoxy-isobutyl isonitrile). The film was prepared using 40 mCi of the Tc-99m(III)-DMSA solution (20 min co-incubation in the dark) and a 3x3cm of the Agfa MammoRay HDR Medical X-ray film, with the presence of DTT in the incubation medium (final concentration in DTT: 10^{-3} M). The phantom with the film, placed between PMMA blocks, is shown in figure 1.a. The reconstructed SPECT images, with the phantom placed almost horizontally and vertically (2^0), are shown in figure 1.b and 1.c respectively.



(1a) (1b) (1c)

Figure 1 1a) Cylindrical shaped phantom consisted of PMMA blocks with the film flood source inside 1b) Left: placed horizontal, Transverse and Sagittal slice was examined, 1c) Right: placed vertical, Transverse and Coronal slice was examined

2.2 MTF calculation

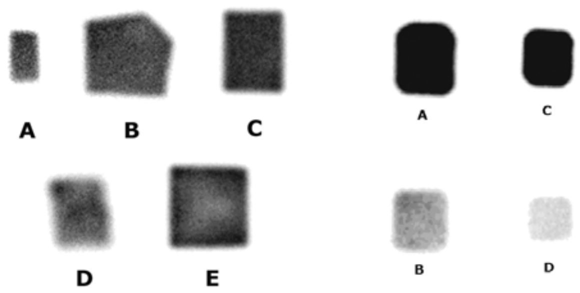
Modulation Transfer Function (MTF) for the brain DatScan® and MIBI heart protocol SPECT images was obtained for different reconstruction and filtering methods. The reconstruction methods for the brain protocol were the following: Filtered Back Projection with Butterworth image filtering 10, 0.5 and Iterative 2D/3D reconstruction with 4 and 8 iterations. For the heart protocol the following reconstruction methods were used: Filtered Back Projection with Butterworth image filtering 10, 0.5, Iterative 2D/3D reconstruction with 4, 8 and 30 iterations and iterative Wallis with 8 iterations. 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 SPECT images, were obtained in directions almost vertical (2^0) to the imaged lines. These profiles were then averaged to obtain the LSF and afterwards fitted with a Gaussian filter.

3 RESULTS AND DISCUSSION

In figure 2.a, representative examples of the imaging results of the various film/ radiopharmaceutical incubation experiments are shown. The polymer composition of the LR 115-type 2 (nitrocellulose), the Agfa Drystar TS 2C [10] and the inkjet transparency film OHP (Ref: KF01146) [11], results in non-specific binding mechanisms of the radiopharmaceuticals used. Marked inhomogeneities in radioactivity distribution, amplified during the rinsing and blotting process, were thus observed. Representative examples of the radioactivity distribution of various combinations of Tc-99m based radiopharmaceuticals and films, prepared as stated in the Materials and Methods section. A: Radioactivity distribution in the 99mTc-MDP/ Agfa MammoRay HDR Medical X-ray film. B: Radioactivity distribution in the Tc-99m- tetrofosmin/Agfa MammoRay HDR Medical X-ray film. C: Radioactivity distribution in the Tc-99m(III)-DMSA/Agfa MammoRay HDR Medical X-ray film. D: Radioactivity distribution in the Tc-99m(III)-DMSA/LR 115-type 2 Kodak film. E: Radioactivity distribution in the Tc-99m(III)-DMSA/Agfa Drystar TS 2C film.

These preliminary experiments revealed the superiority of the Agfa MammoRay HDR Medical X-ray film as adsorption medium. Hence, all further experiments were carried out based on this material, although careful handling is imperative by avoiding touching the film surfaces with bare fingers.
The effect of the addition of DTT (Dithiothreitol) in the incubation of the Agfa MammoRay HDR Medical X-ray with the Tc-99m(III)-DMSA solution (in the dark) for 45 min (A and C) is shown in figure 2.b. The parallel experiments without DTT are also shown (B and D). The C and D films were obtained after exposure of the incubation solution to the ambient air for 1 hr prior to the Agfa MammoRay HDR Medical X-ray film immersion. a/b=3.63 and c/d=6.84, where a,b,c,d are the average radioactivities per unit area (cpm/mm^2) for A,B,C and D films respectively.

Corroborating evidence for the Tc-99m(III)-DMSA adsorption (chemisorption) onto the Agfa MammoRay film, is offered by the fact that the air-exposure of the Tc-99m(III)-DMSA preparation for 1 hr at room temperature, virtually abolished its film-binding capacity, since the assumed –S-S- bond formation, due to the well known easy –SH group oxidation, leads to a paucity of free -SH groups necessary for the proposed precipitative binding mechanism. The addition of DTT in the incubation medium, with its known –SH oxidation-protective ability, increased significantly the Tc-99m(III)-DMSA chemisorption onto the Agfa MammoRay film.



(2.a) (2.b)

Figure 2.a) Representative examples of the radioactivity distribution of various combinations of Tc-99m based radiopharmaceuticals and films, prepared as stated in the Materials and Methods section. 2.b) The effect of the addition of DTT in the incubation of the Agfa MammoRay HDR Medical X-ray with the Tc-99m(III)-DMSA solution (in the dark) for 45 min (A and C).

In figure 3 calculated results for the Modulation Transfer Function, obtained from the brain DatScan® protocol SPECT images are shown for different filtering methods. In all cases, the Gaussian fiiting gave a $R^2 \geq 0.998$, which very close to unity. The best MTF curve was obtained for the Iterrative 3D with 8 iterrations reconstruction method. Iterative 2D and 3D reconstruction methods gave almost the same results (fig.3). Filtered Back Projection (FBP) with Butterworth 10-0.5 reconstruction method has the worst MTF in the low frequency range.

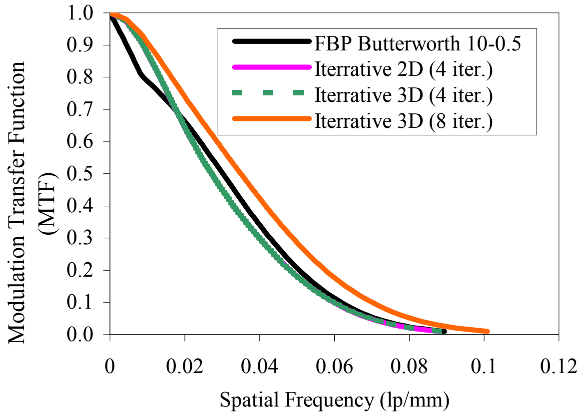


Figure 3) Modulation Transfer Function, obtained from the brain DatScan® protocol SPECT images.

In figure 4 calculated results for the Modulation Transfer Function, obtained from the MIBI heart protocol SPECT images. are shown for different filtering methods. In this protocol MTF values was lower than the brain ones. This is mainly due to the reconstruction matrix (64x64 against 128x128 for the brain protocol). Similar to the LSFs of the brain protocol, the Gaussian fiiting gave a $R^2 \geq 0.998$, which very close to unity. The best MTF curve was obtained for the Iterrative 3D with 30 iterrations reconstruction method. Filtered Back Projection Butterworth 10-0.5 reconstruction method has the worst MTF in the whole spatial frequency range.

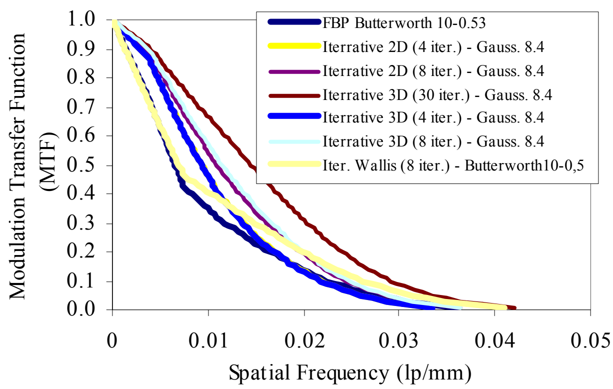


Figure 4) Modulation Transfer Function, obtained from the heart MIBI protocol SPECT images.

4 CONCLUSIONS

The Modulation Transfer Function (MTF), important for the characterization of the spatial resolution of a single photon emission computed tomography (SPECT) system, can be derived by determining the line spread function (LSF) from images of a flood source. The latter was realized by suitably combining the Tc-99m(III)-DMSA with the Agfa MammoRay HDR Medical X-ray film. This flood source was imaged in a Siemens e-Cam γ-camera, using common SPECT imaging protocols (brain DatScan® and Tc-99m-heart MIBI). The aforementioned flood-source, with Tc-99m as the γ-radiation emitting nuclide (E_γ=140 keV), exhibited the highest and most homogeneous binding (integral uniformity: 1.9%) and it was prepared using 40 mCi of the Tc-99m(III)-DMSA solution (45 min co-incubation in the dark) and a 3 cm x 3 cm of the Agfa MammoRay HDR Medical X-ray film, with the presence of DTT in the incubation medium (final concentration in DTT: 10^{-3} M). This method of flood source preparation is easy and can be made on demand in the Nuclear Medicine department with relatively cheap and available materials during the routine γ-camera quality control. Best MTF results were obtained for the brain DatScan® protocol with Iterrative 3D with 8 iterrations reconstruction method. MTF of the brain protocol was in all cases better than the heart protocol.

Acknowledgments

This work has been funded by the Greek State Scholarships Foundation (IKY).

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