

Effects of Fe as a physical filter on spectra of Technetium-99m, uniformity, system volume sensitivity and spatial resolution of Philip ADAC Forte dual-head gamma camera

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Abstract. Single photon emission computed tomography (SPECT) imaging inherits some limitations, i.e., due to scattered gamma photons which degrade spatial resolution causes poor image quality. This study attempts to reduce a fraction of scattered gamma photons before reaching gamma camera detector by using Fe sheet (0.35 mm and 0.40 mm) as a physical filter. Also investigate the effects on spectra of Tc-99m, spatial resolution, system volume sensitivity and uniformity. The thickness of Fe physical filter is selected on the basis of percentage attenuation calculations of different gamma ray energies by various thicknesses of material. Data were acquired using Philip ADAC forte dual-head gamma camera without and with physical filter with LEHR collimator installed. For spectra, uniformity and system volume sensitivity, a cylindrical source tank filled with water added with Tc-99m was scanned. Uniformity and system volume sensitivity images were reconstructed with FBP method by applying Butterworth filter of order 5, cut-off frequency 0.35 cycles/cm and Chang's attenuation correction method using 0.13 cm^{-1} linear attenuation coefficient. Spatial resolution study was done by scanning a line source (0.8 mm inner diameter) of Tc-99m at various source-to-collimator distances in air and in scattering medium without and with physical filter. A substantial reduction in count rate from Compton and photopeak regions of Tc-99m spectra with physical filter is recorded. Improvement in spatial resolution with physical filter up to 4 cm source-to-collimator distance is obtained. System volume sensitivity was reduced and no improvement in uniformity. These thicknesses of physical filter may be tested further by scanning different planar/SPECT phantoms in Tc-99m imaging.

1. Introduction

Single photon emission computed tomography (SPECT) is an imaging that involved a gamma camera which will detect the gamma rays that come out from the patient body part which injected with radiopharmaceutical. SPECT has a main problem of scatter and absorption of gamma photons in the object/patient to be scanned. The scatter gamma photons results a poor quality images and non-linearity in the quantitation of radioactivity uptake [2,3].

In SPECT system, scintillation detectors NaI(Tl) are used in order to detect the emitted gamma photons from the patient body. Compton scattered photons occur within the body of the patient. The presence of scattered gamma photons in the image data degrades the spatial resolution and uniformity in the image. Also, causes the inaccuracy in the quantification of radioactivity distribution.

The problem of Compton scattered photons has been handled by using energy discrimination among the others by narrowing down the energy window. But this method has limitations and unable



to eliminate all scattered gamma photons from projection data because of the poor energy resolution of NaI(Tl). Therefore, the data collected in photopeak energy window comprises primary (unscattered) and scattered gamma photons. Figure 1 shows the simulated distribution of scattered gamma photons into the photopeak of Tc-99m with several scattering orders [10]. This phenomenon was reported by Kojima A et al. [5] which stated that the scattered photons are distributed over the whole symmetric photopeak window and 75% to 80% of these scattered photons are present within the energy window below 140 keV. Therefore, a method for the reduction of the influence of low energy (scattered) gamma photons on SPECT projection data by means of physical filter is used.

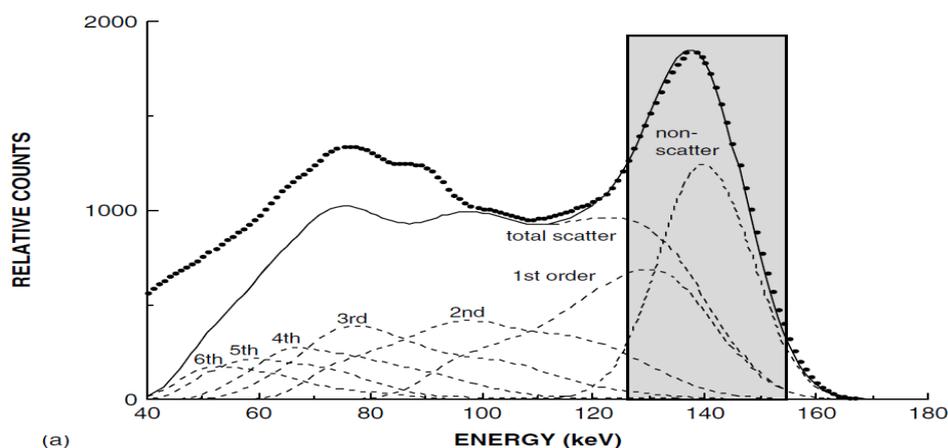


Figure 1. Energy spectra for a gamma emitting Tc-99m line source on the axis of a water-filled cylinder simulated using the Monte Carlo method adopted from Zaidi H 2006 [10].

The basic concept of physical filter is that it decreases the relative concentration of low energy (scattered) gamma photons by preferentially removing them before they can reach the surface of the detector as shown in Figure 2. Thus, the gamma camera may detect more unscattered photons and may provide more valuable information.

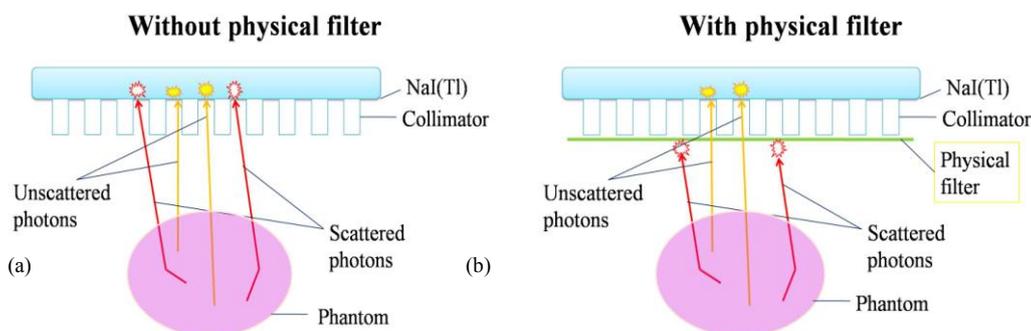


Figure 2. The physical technique concept.

Pillay M. et al [6] used an alloy filter that consist of Lead (Pb), Zinc (Zn), and Tin (Sn) in single photon planar clinical imaging and reported improvement in the image contrast. In 1990, Ficke and Ter-Pogossion [1] suggested that material filters might be advantageous in reducing low energy radiation originating in the field of view of the gamma camera. In their study, they analysed the spectra of F-18 without filter and with 0.017 inch and 0.034 inch thick Pb filters by using NaI(Tl) detector. Further, Spinks and Shah [9] investigated the effects of Pb filters (0.5 mm and 0.1 mm thick) on the overall performance of a Neuro-PET multi-ring (CTI/Siemens 953B) Tomograph and significant reduction in random rates and lower energy events in the measured energy spectrum were observed. A research done by Shah SI [7], using Tin (Sn) 0.25 mm thick sheet as a physical filter in Tc-99m SPECT. From the phantom study, the researcher found that there was reduction in low energy (scattered) gamma photons in the Tc-99m spectrum and improvement in the SPECT image contrast and SNR. In the year 2011, Shah SI et al [8] applied copper (Cu) material sheet 0.125 mm thick and aluminum (Al) 0.2 mm and image quality was marginally improved with physical filters. From the

studies mentioned above, the application of physical filter is found to be significant and provide an easy way to reduce the scattered gamma photons from the image data.

The objective of this study is to investigate effects on spectra of Tc-99m, spatial resolution, system volume sensitivity and uniformity by using Fe physical filter.

2. Methodology

2.1. Selection of physical filter and thickness

Selection of physical filter depends on the type (characteristics) of materials such as linear attenuation coefficient and also the energy of the radioactive source used in the study. From the literature review, no one has used iron, Fe (Z=26) as a physical filter until recent. Thus, Fe was selected in this study. For the calculation purposes, a range of thicknesses were considered, between 0.05 mm to 0.50 mm. Percentage absorption of gamma photons of various energies was calculated by the equation:

$$\text{Percentage Absorption} = (1 - e^{-\mu x}) \times 100\% \quad (1)$$

The linear attenuation coefficient, μ describes the fraction of a beam of x-rays or gamma rays that is absorbed or scattered per unit thickness of the absorber. The μ value was calculated from mass attenuation coefficient taken from Hubbell and Berger [4]. All percentage absorption values for material were tabulated in Table 1.

Table 1. Percentage absorption of Fe by various thicknesses for 126-139 keV and 140 keV of Tc-99m.

Thickness (mm)	Percentage absorption	
	126-139 keV	140 keV
0.05	9.23	8.34
0.10	17.81	16.16
0.15	24.79	22.59
0.20	32.54	29.79
0.25	38.53	35.42
0.30	44.24	40.84
0.35	47.52	44.01
0.40	53.00	49.29
0.45	55.98	52.22
0.50	61.88	57.96

From Table 1, the thicknesses were selected by the absorption percentage in terms of energy of gamma photons. 0.05 mm was the most appropriate thickness which absorbed 8.34% of 140 keV compared to 9.23% of 126-139 keV. The percentage difference between 140 keV and 126-139 keV is 8.9%. Unfortunately, the thickness (0.05 mm) was not available. Therefore, this study was done by applying 0.35 mm and 0.40 mm because of the availability of these thicknesses. The physical filter was designed sized 55 cm length and 44 cm width matching the size of gamma camera head. The surface of the physical filter was flat and due to the material fragility, it was laminated/coated with a thin laminating film.

2.2. Materials

Gamma camera system has been used is Philip ADAC Forte dual head attached with LEHR collimator and Pegasys software installed. In this study, Tc-99m was used as radioactive source because this source is easily available and commonly practiced in clinical studies.

2.3. Measurement of Tc-99m spectra without and with physical filter

The data for Tc-99m spectra were collected without and with physical filter by scanning a NEMA SPECT Triple Line Source Phantom™ (source tank only) filled with water and Tc-99m (15 mCi) distributed uniformly. The physical filter was mounted on the face of LEHR collimator as shown in Figure 3. Ten contiguous energy windows were adjusted over the entire spectrum of Tc-99m for

recording the count rate. The spectra were plotted from the count rate obtained without and with physical filter versus the energy (keV). The count rates were corrected for the decay.

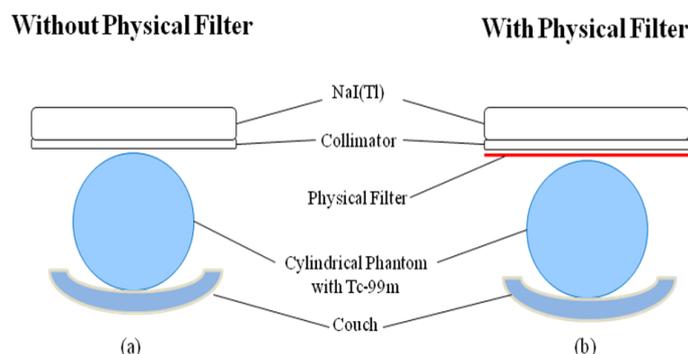


Figure 3. Experimental setup for Tc-99m spectra measurement (a) without and (b) with physical filter.

2.4. Measurement of spatial resolution without and with physical filter in air and scattering medium

The data were collected by scanning a line source (inner diameter: 0.8 mm) of Tc-99m (1.36 mCi) without and with physical filter within a 20% symmetrical energy window centred at the photopeak (140 keV). The physical filter was mounted on the face of LEHR collimator. The line source was scanned in air and scattering medium (acrylic plates) at various source-to-collimator distances ranging from 1 to 10 cm as shown in Figure 4.

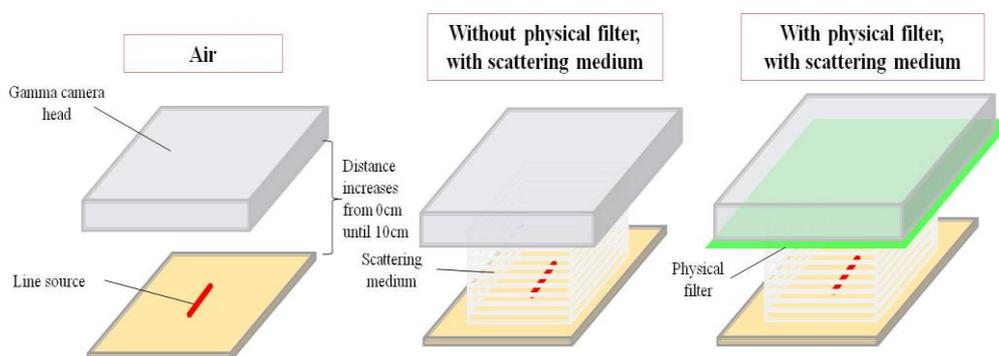


Figure 4. Experimental setup for measurement of spatial resolution without and with physical filter in air and in scattering medium.

2.5. Measurement of system volume sensitivity and uniformity without and with physical filter

SPECT data were collected by scanning cylindrical phantom (inner height: 20 cm, inner diameter: 20.2 cm) loaded with 14.04 mCi of Tc-99m for system volume sensitivity and 20.41 mCi of Tc-99m for uniformity test without and with physical filter, respectively. The experimental setup is shown in the Figure 3. The radius of rotation of gamma camera head was 15 cm. The physical filter was mounted on the face of LEHR collimator. Uniformity images were reconstructed with FBP method by applying the Butterworth filter of order 5 and cut-off frequency 0.35 cycles/cm and Chang's attenuation correction method using 0.13 cm^{-1} linear attenuation coefficient was applied.

3. Results and discussion

3.1. Tc-99m spectra without and with physical filter

For analysis purposes, photopeak energy window was divided into three sub-windows, i.e., (i) 126-139 keV, (ii) 140 keV and (iii) 141-154 keV (Figure 5(a)). Figure 5(b) shows the average percentage reduction from sub-window (i) for 0.35 mm physical filter was 29.49% and for 0.40 mm physical filter was 40.81%. While in sub-window (ii), the average percentage reduction for 0.35 mm physical filter

was 38.76% and for 0.40 mm physical filter was 45.16%. For sub-window (iii), the average percentage reduction for 0.35 mm physical filter was 44.89% and for 0.40 mm physical filter was 50.41%. The higher percentage reduction in sub-window (ii) shows that Fe with 0.35 mm and 0.40 mm thicknesses are not suitable as a physical filter because more unscattered gamma photons were reduced. Improvement might have if the preferred thickness of the physical filter was used to remove more scattered gamma photons.

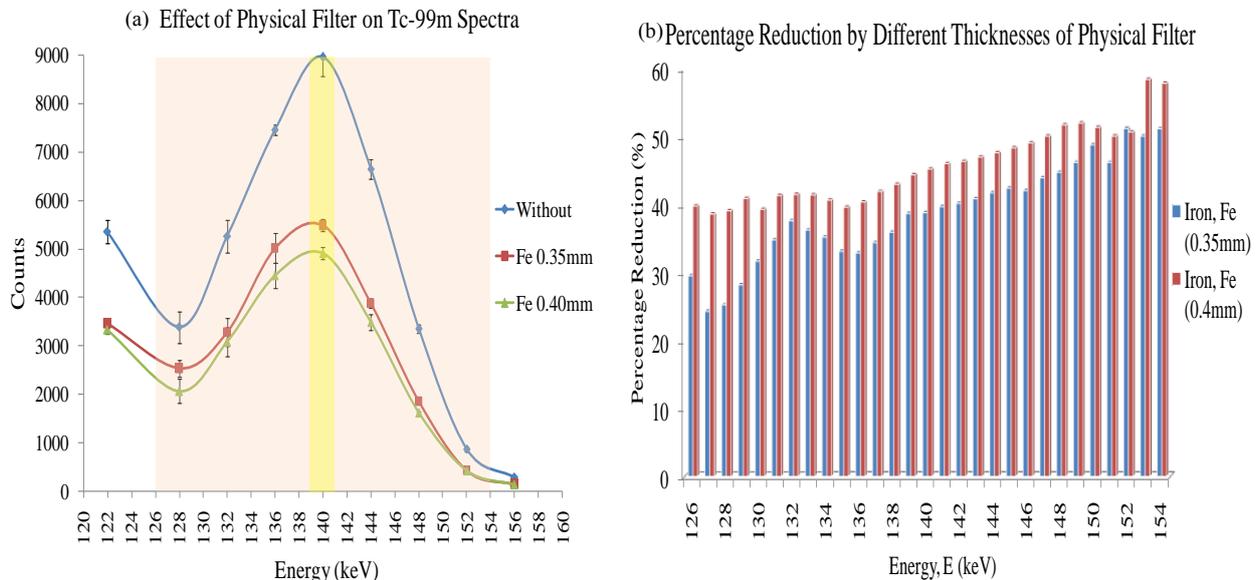


Figure 5. (a) The effect of Fe as a physical filter on Tc-99m spectra and (b) The percentage reduction by different thicknesses of physical filter.

3.2. Spatial resolution without and with physical filter in air and scattering medium

The full-width-half-maximum (FWHM) was measured for without and with physical filter. From Figure 6, the FWHM for 0.35 mm physical filter was improved as source-to-collimator distance increases from 1 to 3 cm compared to without physical filter. There was also an improvement in FWHM with 0.40 mm physical filter from 1 to 4 cm source-to-collimator distance. The FWHM for both 0.35 mm and 0.40 mm physical filter was poor as source-to-collimator distance increased from 5 cm and above.

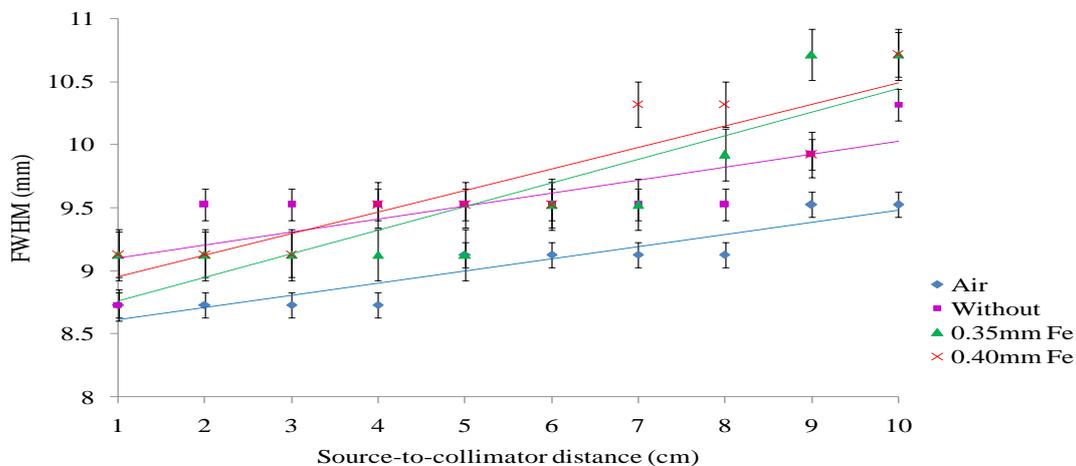


Figure 6. Spatial resolution without and with physical filter.

3.3. System volume sensitivity and uniformity without and with physical filter

The SPECT data were interpreted and analysed by using Pegasys software. The results show that the system volume sensitivity was 0.1677 cps/Bq/ml without applying physical filter. For the 0.35 mm

and 0.40 mm physical filter, the system volume sensitivities were 0.1618 cps/Bq/ml (3.52%) and 0.1594 cps/Bq/ml (4.95%), respectively. There was reduction in the system volume sensitivity compared to without physical filter.

For uniformity, a straight line was drawn through the reconstructed image to obtain count profile. There is fluctuation in count profile for both thicknesses as well as without physical filtered data images and no improvement (Figure 7). This is probably due to unsuitable of chosen physical filter thicknesses.

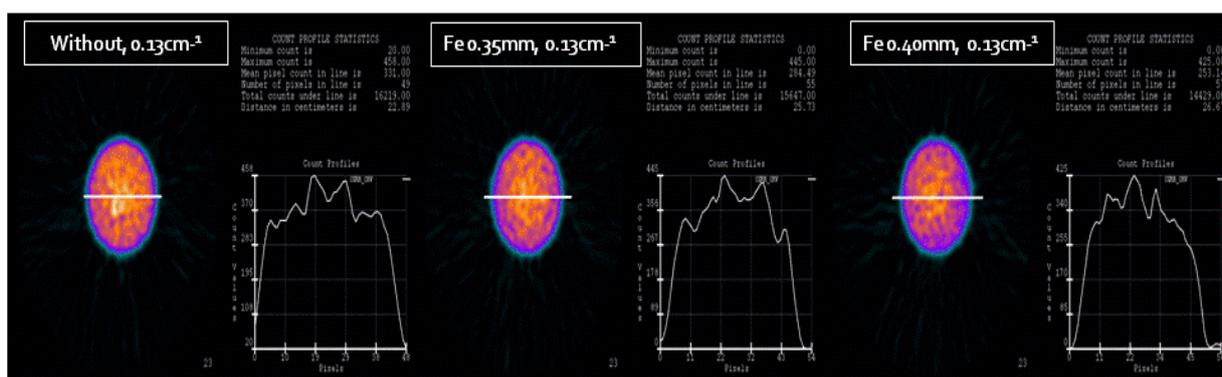


Figure 7. Count profiles for without and with Fe as a physical filter.

4. Conclusion

Results show the significant reduction in count rate with physical filter from photopeak region of Tc-99m spectra. At certain source-to-collimator distance, spatial resolution was improved. However, system volume sensitivity was reduced. For the uniformity, no improvement has been achieved. Only on the basis of spatial resolution results at 1 to 4 cm source-to-collimator distance, these thicknesses of physical filter may be tested further by scanning different planar/SPECT phantoms in Tc-99m imaging.

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