International Journal of Computing Academic Research (IJCAR)
ISSN 2305-9184, Volume 5, Number 3 (June 2016), pp.143-149

http://www.meacse.org/ijcar

Effects of Copper 0.127 mm Thick Flat Sheet on Uniform and Hot Region Images as A Material Filter for Scatter Correction in Tc-99m SPECT

Inayatullah Shah Sayed and Siti Zawani Harun

Department of Diagnostic Imaging and Radiotherapy, Kulliyyah of Allied Health Sciences, International Islamic University Malaysia, Kuantan Campus, 25200 Kuantan, Pahang, Malaysia

Abstract

In the SPECT image data, presence of scatter component leads to poor image quality. Consequently, inaccuracy in the diagnosis of disease occurs. This study aims to improve the image quality by reducing some fraction of scattered gamma photons prior to detection using a material filter technique. Data were acquired by scanning a cylindrical source tank with hot/cold regions insert filled with water and uniformly distributed Tc-99m radionuclide. Philip ADAC Forte dual head gamma camera with LEHR collimator was used. Material filter, a flat sheet of Cu 0.127mm thick was attached on the outer surface of the collimator. SPECT data were acquired without and with material filter. Filtered back projection technique was applied. Images were visually examined in order to observe the improvement in image quality of uniform and hot regions as well as the detectability of hot regions. Standard deviation in the count density of uniform region and contrast of hot region images was calculated. Findings of the study reflect an overall enhancement in the image uniformity, hot regions detectability and contrast with material filter. It is concluded that, material filter technique need further investigations for applicability in clinical studies by scanning other phantoms mimicking human organs.

Keywords: SPECT, Scatter Correction, Material filter, Image Quality Enhancement

Introduction

Single Photon Emission Computed Tomography (SPECT) is extensively used as an important tool to provide physiological information of the organ of interest for investigations into the human health and diseases. SPECT exploits the use of gamma emitting radionuclides e.g. Tc-99m labeled with suitable pharmaceuticals for patient injection. Therefore, this technique inherits the problem of scattered gamma photons among the others. Scattered gamma photons degrade the overall image quality. SPECT imaging equipment use NaI(Tl) scintillator for gamma photon detection. However, due to the poor energy resolution nearly in all of the patient examinations 30 – 40% of recorded photons within the standard photopeak energy window data are scattered gamma photons [1].

Last three decades have witnessed a variety of SPECT scatter correction/reduction techniques, developed by a number of researchers. For example, selection of asymmetric energy window [2], use of effective attenuation coefficient value 0.12/cm in attenuation compensation instead of actual value 0.15/cm in water / tissue for 140 keV [3]. Another kind of techniques which is based on subtraction of scatter energy window data, such as, dual and triple energy window developed by [5 – 7] where data are collected in the scatter energy window and the image obtained from that data is subtracted from photopeak energy window image after scaling by a factor *k*. Spectral analysis models developed by [8–11], in this method energy information is recorded for all interactions; scatter and primary contribution is distinguished by analyzing the pixel using scatter model. Unfortunately only few of these scatter correction techniques are routinely used, such as; simple dual or triple energy window subtraction methods. Furthermore, not much emphasis is given to standardize the scatter compensation techniques for clinical use.

In the present study, a material filter technique has been applied, which was introduced in single photon emission imaging by [12] using an alloy (composite) filter consisting of Pb, Zn and Sn. Improvement in the contrast of images of various patient studies were reported, indicating the possibility of employing the technique in SPECT. In 1992, [13] employed a material filter of lead sheets (1.6mm - 6.4mm), attached to the front face of a gamma camera, for imaging therapeutic doses of I-131. A Monte Carlo study was also undertaken by them, simulating their experimental setup and found that system resolution is degraded by the Pb sheet. However, they suggested the use of such absorbers in SPECT to reduce the detection of unwanted photons. Lead filters were also used by [14] in order to reduce the number of scattered events recorded in PET scanning. Recently, [15] reported that the uniformity and linearity of gamma camera was improved with the use of copper and aluminum material filters. Nazifah et al [16] applied 0.198 mm Zinc (Zn) flat sheet to assess the performance parameters of a gamma camera and reported improvement in spatial resolution with material filter. More recently [17] used tin (Sn) 0.25mm flat sheet as scatter absorber in Tc-99m SPECT and achieved enhancement in the image quality of cold regions.

In this study, Cu 0.127mm thick flat sheet is investigated in terms of enhancement in the quality of hot regions by removing a fraction of scatter gamma photons prior to their detection. Thus, may be considered as on line / pre-processing scatter reduction. Further the advantages of this technique over the others are; material is readily available, cost effective, low weight and easy to mount on the surface of gamma camera collimator.

Methods and Materials

Data acquisition and image reconstruction

In this study the Philip ADAC Forte dual-head gamma camera system equipped with low-energy high-resolution parallel-hole collimator was used. The Tc-99m radionuclide was distributed homogenously in the phantom (20.8mCi). A modified PET/SPECT cylindrical phantom with cold/hot regions insert was scanned [18]. Eight pairs of holes with various sizes (30.1, 22.6, 18.1, 14.5, 11.6, 9.4, 7.5, 6.1 and 4.9mm diameter) at different positions simulating hot regions were drilled in a solid acrylic block in ‘V’ shape arrangement (similar to R A Carlson’s Phantom) as shown in Fig. 1. The material filter used in this study was the flat sheet of copper sized 60cm x 50cm and thickness of 0.127 mm depicted in Fig. 2.

Phantom tank was filled with water and a couple of drops of dye were injected into the water to indicate the homogenous distribution of the radionuclide and it was ensured that there is no air and leakage of water mixed with radioactivity. The image data were acquired within a symmetrical single standard energy window 20% (±10%) over the photopeak centered at 140 keV. The matrix size 128x128x16 was used. Ninety (90) views were taken over 360^o with anti clockwise orientation. The time per view was preset at 20 seconds. First the data were acquired without material filter, then, copper sheet was mounted on the outer surface of collimator. The parameters were same in both (without and with material filter) data sets. The data were reconstructed with filtered back projection image reconstruction technique. Butterworth filter was applied with cut-off frequency 0.35 cycles/cm and order 5. Chang’s attenuation correction method was also applied with linear attenuation coefficient, μ, $0.13cm^{-1}$. Moreover, before data acquisition, uniformity test, spectrum check and centre of rotation (COR) were carried out to avoid loss of resolution and distortion in the reconstructed images.

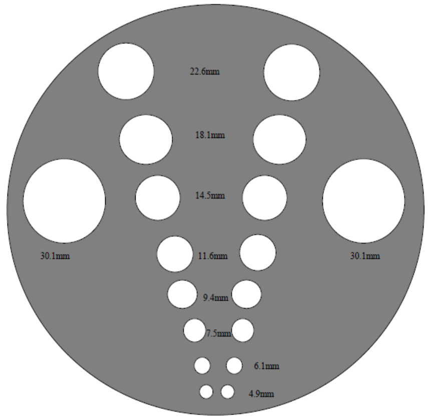

Fig. 1 Cross section of hot regions insert (courtesy of Sayed 2016)

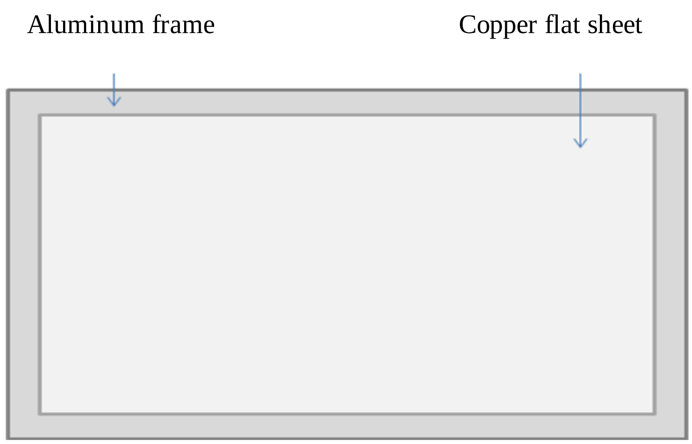

Fig. 2 Material filter a flat sheet of Copper (Cu) 0.127mm thick 60 x 50 cm.

Standard deviation (SD) in the count density of uniform region image

One of the parameter to investigate the quality of nuclear medicine image is the measurement of SD in the count density of the area of interest. Since, it estimates the presence of noise component in the image. For the measurement of SD in the count density of tomographic images of uniform region of the phantom obtained from without and with material filtered data were displayed and analyzed by using ImageJ software [19]. To calculate SD a large circular region of interest (ROI) throughout the uniform image region was drawn carefully avoiding the overlapping of boundaries of the phantom. In order to avoid any discrepancy in the SD measurement the size of the ROI was maintained and used for other image. Each measurement was repeated for three times. Further, for the significance ($p < 0.05$) of results one-way ANOVA test was performed.

Hot region contrast measurement

Hot regions contrast of different sized regions was measured by drawing circular ROIs according to the size of the relevant hot region using ImageJ. ROIs were positioned carefully within the boundaries of each hot region. For the consistency in the count density of hot regions reconstructed from without and with material filtered data, sizes of relevant ROIs were maintained same. Each measurement was repeated for three times. Background counts were recorded by drawing irregular ROI over the image avoiding the known locations of hot regions. Eq. 1 was used for the calculation of hot region contrast ($C_{\text{hot region}}$).

$$C_{hot\ \ region} = \frac{D_{region} - D_{bkg}}{D_{region} + D_{bkg}} \tag{1}$$

Where $C_{hot\ region}$ represents the measured hot region image contrast, D_{region} and D_{bkg} indicate the average count densities in the area of interest in the hot region and in the background, respectively.

In order to calculate the significance difference in hot region contrast results, one-way ANNOVA was applied at $p < 0.05$.

Results

Fig. 3(a) and (b) show the transverse image slices of uniform region image (a) without material filter and (b) with copper material filter. Perceived image quality is improved as it can be seen that the image 3b is smoother than 3a. Standard deviation in the count density of uniform region images shows the reduction with copper material filter as compared to without material filter as shown in (Table 1) which was calculated to support the visual analysis.

Fig. 3 (a) and (b) Transverse images of a uniform region of the phantom (a) without and (b) with material filter

Table 1 Standard deviation in the count density of the image of uniform region

Standard deviation	
No Material filter	Copper Material Filter (0.127mm thick)
31.34 +/- 0.27	27.03 +/- 0.07

Visual analysis of hot region images as shown in Fig. 4 (a) and (b) without and with material filter, respectively, show the improvement in the detectability of hot regions and reduction in scattered gamma photons between the space of hot regions with material filter. Further, same hot region images were used to measure the contrast. For analysis only those hot region pairs were included which were seen clearly and others were excluded. For background count density measurement an irregular large ROI was drawn without overlapping the hot regions. The measured contrast with the material filter shows the improvement relevant to image produced from without material filtered data.

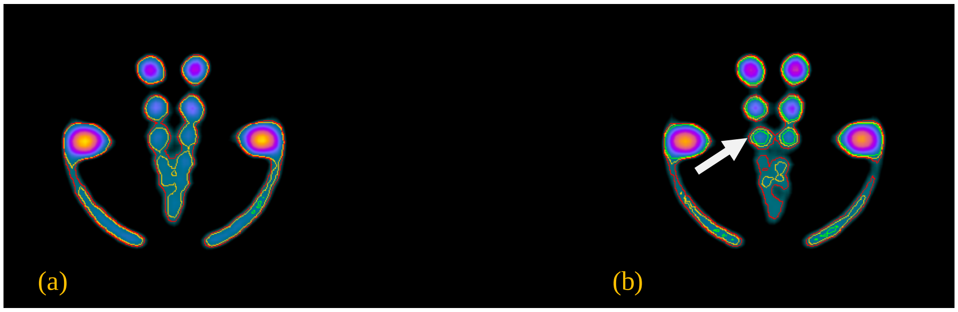

Fig. 4 (a) and (b) show the transverse images hot regions (a) without and (b) with material filter

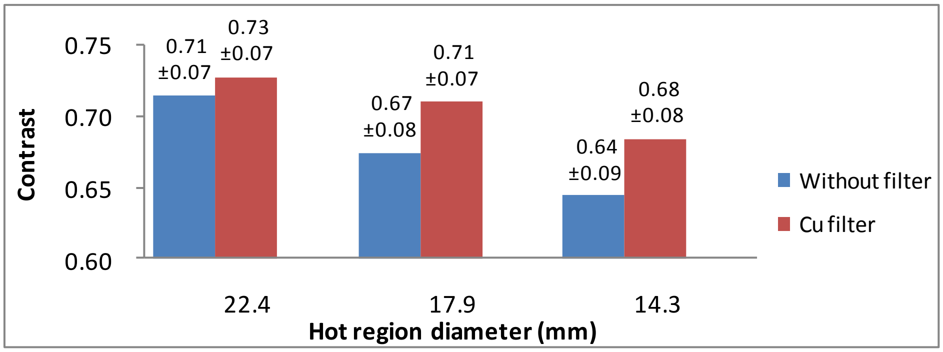

Fig. 5 Contrast of various sized hot regions without and with material filter

Discussion

Single photon emission computed tomography as an imaging modality has significantly contributed in the diagnosis of a variety of diseases, as well as investigations into the other human health related issues. However, accuracy of clinical results is limited due to the problem of scatter which is always present in the image data. Literature shows that a large number of scatter correction techniques have been developed. But it is not possible to remove all scattered gamma photons from the raw data by employing the existing scatter correction techniques. Also, commercially available techniques are expensive and difficult to implement. Contrary, in this study the investigated material filter technique is low cost as well as easy to implement and removes some scatter before they reach to the gamma camera detector.

Visual analysis of uniform region images with material filter (Fig. 3b) are seen more uniform as compared to image without material filter (Fig. 3a) which indicates the effectiveness of material filter technique. Since, scatter is one of the causes of non-uniformity in nuclear medicine images which lead to the generation of uneven amplitude of signals / pulses as compared to non-scattered gamma photons. Thus, it causes the appearance of hot and cold spots in the image of uniform radioactive distribution. In addition, the standard deviation results shown in (Table 1) also indicate that with copper material filter, there is significant ($p < 0.05$) reduction in SD value.

Hot regions detectability is improved with material filter (Fig. 4b), particularly the third pair (pointed by the white arrow) of hot regions of the 'V' shape. It is clearer and circular as compared to image (Fig. 4a). This strongly indicates the removal of some amount of scatter from the SPECT data with material filter. In addition, the position of 4th pair of hot regions can be realized. In image (Fig. 4a) without material filter, except 22.4 mm diameter hot region pair, other pairs are seen connected with each other, in principle there should be a gap between each pair as well as in each hot region. Furthermore, it is difficult to observe the remaining pairs of hot regions in both images. However, the lower part of "V" shape shows reduction of some fraction of scattered gamma photons with material filter.

Fig. 5 shows, 3 – 6% improvement has been achieved in the contrast of three hot region pairs (22.4, 17.9 and 14.3mm diameter) with copper material filter compared to the image which was reconstructed from the data that were obtained without material filter. This aids to the assumption that material filter removes scatter gamma photons and prove that the technique has a potential in correcting the Tc-99m clinical SPECT data.

Conclusion

The results reflect that image uniformity, hot region detectability and contrast are improved with copper material filter technique. Therefore material filter technique may be tested further by imaging phantoms which simulate human organs for SPECT clinical examinations.

Acknowledgement

Authors gratefully acknowledge the Department of Nuclear Medicine, Radiotherapy and Oncology, Universiti Sains Malaysia, Kubang Kerian, Kelantan for allowing to use the equipment for data collection and some technical assistance. This research was funded by the International Islamic University Malaysia (EDW-A10-156-0703).

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