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Effects of Unconventional (Material) Filters on the Quality of Images Produced By Three Gamma Camera Systems in Tc-99m SPECT

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Abstract: **With nuclear medicine imaging technique, abnormalities in the human body can be detected at early stages and therefore an effective treatment planning is possible to make. Consequently, human lives can be saved and the health condition of patients can also be improved. However, this depends upon the reliable diagnostic information that is obtained by an imaging system. Presence of scattered gamma photons leads to the inaccurate representation of counts in the image projection, thus the loss of image contrast and overall image degradation. This study uses the unconventional (material) filters i.e., Aluminum (Al) 0.1 & 0.2mm and Copper (Cu) 0.125 & 0.127mm thick flat sheets for the reduction of scattered gamma photons before they reach to the gamma camera detector. Quality of images reconstructed from the data acquired by three gamma camera systems (Toshiba GCA109A/HG, Philip ADAC Forte dual head and GE Infina dual head) installed at two different nuclear medicine departments was assessed. Data were acquired by imaging R. A. Carlson's phantom with hot region and cardiac inserts and Tc-99m radionuclide was used. LEHR collimator was used and unconventional (material) filter(s) were mounted on the outer surface of collimator, separately. Symmetrical energy window (20% for Tc-99m) was selected. Images were investigated in terms of contour analysis and lesion detectability. Improvement was achieved in the parameters that were investigated for images obtained from the data with unconventional (material) filters, as compared to without material filtered data images. Thus, the technique may be tested further by using more complicated phantoms, such as; Heart/Thorax phantom. Moreover, results are suggestive, that the technique may be proved to be useful when applied in clinical studies.**

Keywords: **Scatter correction, SPECT, Image quality, Noise, Contrast, Unconventional filters, Gamma camera.**

I. INTRODUCTION

Nuclear medicine imaging is a non-invasive radionuclide technique which is widely used for diagnosis of abnormalities in the human body. In clinical studies it is always desired to obtain better quality images and accurate quantitative information from the gathered data, in order to provide better diagnostic and treatment services to patients. Quality of images and quantitative accuracy of clinical data mainly depends upon the performance parameters of gamma camera, such as; energy resolution, spatial resolution, over all sensitivity, uniformity and linearity. There are some factors which affect the performance parameters of gamma camera systems used in this modality. For example, scattered gamma photons are among the other factors. These photons emanate from the body of the subject to be scanned and inclusion of scattered gamma photons in the patient data results in an overall degradation of image quality.

Energy resolution for most SPECT systems is approx: 8 - 12% for 140 keV energy gamma photons. Hence, no total scatter rejection via energy discrimination (20% window). Approx: 20 - 40% of the detected events in SPECT data are present due to scattered photons [1] and 70 – 80 % of the total scatter in 126 – 154 keV window is present in the region of 126 – 139 keV [2].

A variety of approaches towards scatter correction are present, viz., computational techniques - Monte Carlo Methods: Ljungberg and Strand [3], Floyd et al [4] and Energy – Window techniques which are system based, such as; single, dual and multiple energy windows [5], Sanders and Spyrou [6], [7]. Broad Beam Attenuation Method: Use of effective linear attenuation coefficient 0.12/cm [8].

Another approach for the improvement of performance of scintillation camera systems is the use of unconventional (material) filters. This technique has been applied by a number of researchers. In Positron Emission Tomography (PET), Muehllehner [9] studied the effects of a material filter for PET imaging systems, a material filter consisting of 1.27 mm Lead (Pb) 0.76 mm Tin (Sn) and 0.25 mm Copper (Cu). The useful count rate was reported to be increased by a factor of five. Spinks and Shah [10] determined the effects on (i) singles rate and the energy spectrum. Lead (Pb) filters of 0.5 mm and 1.0 mm thickness were employed resulting in a substantial decrease in randoms and scattered events rate were observed in the measured energy spectrum.

In single photon emission imaging – planar imaging - Muehllehner et al [11] used a sheet of material filter comprising of 0.23 mm Tin (Sn) and 0.13 mm Copper (Cu) for the attenuation of specially lower energy events in the gamma ray spectrum, while leaving the photopeak events comparatively constant. This resulted in the improvement of count rate performance at high count rates. Pillay et al [12] applied an alloy filter consisting of Lead (Pb), Zinc (Zn), and Tin (Sn) in single photon planar imaging, from a number of clinical studies and improvement in image contrast was noticed.

In single photon emission computed tomography (SPECT), Shah [13] and Sayed [14] used a Tin (Sn) material sheet 0.25 mm thick. Tc-99m spectra with and without material filter were obtained, achieving reduction in low energy gamma photons in the spectrum and improvement in the SPECT image contrast and signal to noise ratio (SNR). Yee [15] studied on the uniformity and linearity of an imaging system in SPECT as a result of unconventional filters, improvement was achieved.

Thus, the work in this study aims to address the scatter problem by the use of unconventional (material) filters to investigate the effects on perceived image quality and lesion detectability by reconstructing images from the data acquired by employing three different gamma camera systems.

II. MATERIALS AND METHODS

Unconventional (material) filters, i.e., Aluminum (Al) 0.1 & 0.2mm and Copper (Cu) 0.125 & 0.127mm thick flat sheets were chosen on the basis of calculation of percent attenuation of gamma photons of different energies. Three gamma camera systems were used - Toshiba GCA-901A/HG, Philip ADAC Forte dual head and GE Infina dual head. Hot regions and cardiac inserts were placed into the cylindrical source tank, which were then scanned.

SPECT Data Acquisition and image reconstruction:

Toshiba GCA-901A/HG:

R. A. Carlson’s phantom was prepared by filling water into the tank and the hot regions insert (Fig. 1) was placed in the phantom’s tank. The phantom was put aside overnight, to allow dissolved air bubbles to dissipate from the water. The solution of Tc-99m (19.29 mCi) was added into the tank. The solution in the tank was mixed thoroughly by repeated inversion of the tank until the phantom was ready. Then the phantom was placed on the patient coach, with the axis parallel to the face of the collimator and in the centre of field of view (FOV) of the gamma camera. The phantom was taped securely in position on the patient coach to prevent movement which might affect the image quality. The image was acquired by using LEHR collimator mounted on the face of the detector of the gamma camera without using any material filter. Data was acquired within a symmetrical energy window 20% (centred at 140 keV) and 128 x 128 imaging matrix. Sixty views were taken over 360 degrees and the time for each projection/view was 20 seconds. The radius of rotation of the gamma camera was 20 cm from the central axis of the phantom. After that, the acquisition of the images was repeated by mounting a filter Cu 0.125mm thick on the outer surface of the collimator. The acquisition parameters were same as those without the material filter. The study was continued by using 0.2mm thickness of aluminum as the material filter.

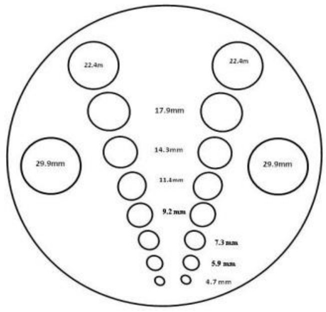

Fig.1: Cross-sectional view of hot regions insert

Transverse images of hot regions insert were reconstructed, by the filtered back projection method. A ramp filter with an 8^{th} order Butterworth window having 0.15 cycles/cm cut-off frequency was used. For the attenuation correction technique, Chang's method was selected. The attenuation value of 0.141/cm for Tc-99m was applied to the data in the case where the material filter was mounted, and an effective attenuation coefficient value of 0.131/cm was chosen where no material filter was employed. All the raw data were amended for the decay, uniformity and center of rotation (COR). The same reconstruction algorithm and filter (Butterworth) was used for images without and with copper and aluminum material filters.

Philip ADAC Forte dual head:

R. A. Carlson's phantom with hot region insert was filled with filtered water until it was slightly empty. The solution of Tc-99m (17.47mCi) and then blue dye was introduced into the phantom. The dye was used as an indicator to ensure the distribution of the radionuclide in the phantom is uniform. The phantom was gently shaken, to make certain the homogenous distribution of the radionuclide. Moreover, the bubble formation was removed and filtered water was injected to fill the tank completely.

The phantom was placed on the examination table of the gamma camera. The phantom was positioned in the center of the table, to ensure the distance between the phantom and the gamma camera is equidistance for all projections with respect to the gamma camera collimator. The orientation of the "V" shape of hot regions was correctly oriented. The 20% energy window centered at 140keV was adjusted. The matrix size 128 x 128 x 16 was chosen. Low energy high resolution (LEHR) collimator was used and 120 projections (20 seconds/ projection) were taken over 360 degree. The data was collected without and with the material filter mounted on the outer surface of the collimator. All the data collection parameters were same in both cases, i.e., without and with material filter. It was ensured before collecting the data that the quality (QC) of the gamma camera was performed.

Images from the raw data were reconstructed with filtered back projection technique. Butterworth filter was used with the order of 6 and of 0.4 cycles/cm cut-off frequency. Moreover the Chang's attenuation correction was applied to all the data sets with 0.13/cm linear attenuation coefficient value.

GE Infina dual head:

In this work, R. A. Carlson's cardiac insert was scanned (the myocardial wall chamber (250ml) was used). In order to mimic the myocardial defect, a 9.8 mm x 9.8mm x 9.8mm thick cold defect of polystyrene was positioned at the anterior side of the myocardial wall chamber (Fig. 2). The myocardial wall chamber filled with water and Tc-99m of concentration of about 4.0µCi/ml. 1000µCi (37MBq) was injected to achieve the required concentration.

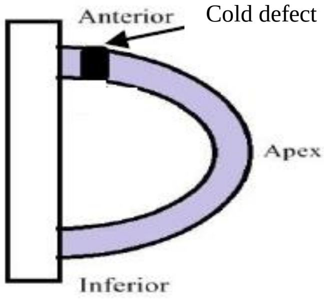

Fig.2: Myocardial wall chamber (left ventricle)

After the setting up of myocardial wall chamber, it was inserted into the cylindrical tank filled with 10 litres of water. The amount of Tc-99m radioactivity was 1200µCi (44.4MBq), giving 1.2µCi/ml (0.044MBq/ml) as the background activity which was introduced into the tank. The position of the chamber was adjusted according to the orientation of the human heart and particularly, this myocardial wall chamber represents the left ventricle of the heart.

The cylindrical tank which consists of the myocardial wall chamber was positioned supine on the patient bed of the gamma camera. The scanning parameters were selected and the marks were made in order to keep the position constant for each data acquisition set. Sixty projections were recorded. The shoot acquisition starts from 45˚ right anterior oblique to 45˚ left posterior oblique position in 180˚ arc dimension. Approximately 22.6 cm of the distance between the detector and the phantom was kept constant for each data acquisition. A single energy window at 140keV was used. Projection data were acquired into a 128x128 matrix and were corrected for uniformity. The data was reconstructed by application of filtered back projection technique. Butterworth digital filter was used with fixed (cut-off frequency 0.40 and order 10). For attenuation correction, Chang’s method was used with 0.12/cm linear attenuation coefficient. Three standard views of SPECT slices were generated which are short axes (SA), vertical long axis (VLA) and horizontal long axis (HLA). However, in this paper only SA view is investigated.

SPECT image quality analysis:

All images, hot region and cardiac were investigated by contour analysis, using ImageJ software [16].

III. RESULTS AND DISCUSSION

It is well established that the scattered gamma photons adversely affect the SPECT image quality of patient examinations if the image raw data is not corrected for. Therefore, the accuracy in the diagnosis of the disease is hampered and the chance of making erroneous decision by clinical specialists is high. However, numerous scatter correction techniques have been developed, unfortunately none of them is considered as a standard technique. Also, in terms of cost and implementation problems there is seldom use of scatter correction techniques in the nuclear medicine departments for patient studies. Thus, due to economical and ease-of-implementation reasons, material filter technique was studied by installing on different gamma cameras. Phantom images of hot as well as cold regions were examined via contour analysis.

Hot region images:

Toshiba GCA-901A/HG:

Fig. 3 (a) and (b) show the transverse slices of hot regions insert in a uniform cold background from the data, without and with aluminum 0.2mm thick material filter, respectively. Hot regions “V” shaped in Fig. 3(b) appear sharper as compared to the image shown in Fig. 3(a). There is less blurring around all the hot regions relative to without material filtered data images. This reflects that scattered gamma photons were absorbed by the material filter. Moreover, the gap between the smaller diameter hot regions is not that obviously visible though the blurring effect which is reduced with the material filter in Fig. 3(b). In addition, detectability of hot regions is improved i.e., more hot region pairs can be viewed with the use of aluminum material filter.

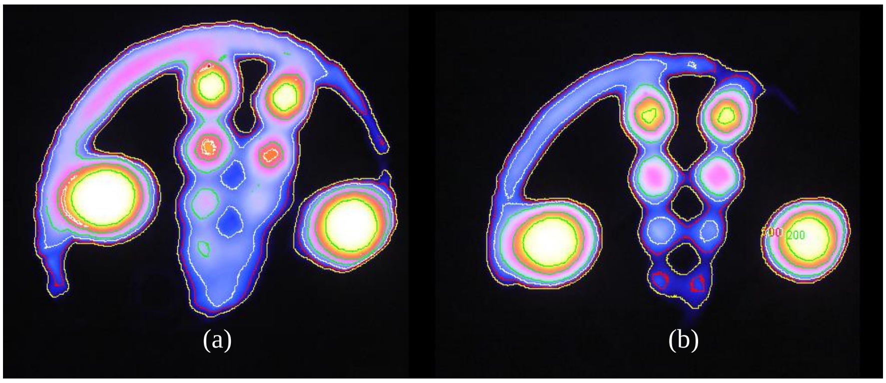

Fig.3: (a) and (b) Show the hot region images (a) without and (b) with aluminum 0.2mm material filter

Images shown in Fig. 4(a) and (b), were reconstructed from the data acquired with the same imaging equipment without and with attaching the copper material filter on the face of collimator, respectively. Fig. 4(b) shows improvement in resolution is achieved as compared to the image in Fig. 4(a). Regarding the detectability of hot regions where more pairs are visible with the material filter. This proves that the material filter has contributed in stopping some fraction of scattered gamma photons before reaching the gamma camera detector.

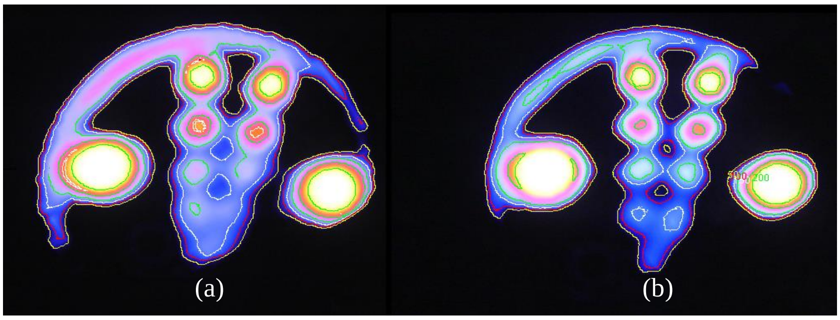

Fig.4: (a) and (b) Show the hot region images (a) without and (b) with copper 0.125 mm material filter

Philip ADAC Forte dual head:

Hot region images, in Fig. 5(a) and (b) were produced from the data collected without and with the use of copper 0.127mm thick material filter fixed over the outer surface of the collimator. More hot regions in the image Fig. 5(b) are visible and almost a complete “V” shape of hot regions is visible, which resembles with the actual arrangement of hot regions as compared to Fig. 5(a). However, contour show that somehow, little gap between hot regions relative to the Fig. 5(a) where space between them is visible. In addition, the background of the hot regions in Fig. 5(a) is more uniform as compared to without material filtered data image.

Fig.5: (a) and (b) Show the hot region images (a) without and (b) with copper 0.127 mm material filter

GE Infina dual head:

Images of cardiac insert simulating left ventricle and with the cold defect in the myocardial wall were obtained from the data gathered without and with the aluminum 0.1mm material filter as depicted in Fig. 6(a) and (b). Reconstructed image, presented in Fig. 6(b) shows larger gap at the position of the cold defect relative to the image without material filtered data Fig. 6(a). Scattered gamma photons travelling from the background region overlap the cold areas in the image are seen smaller in size as compared to the actual size. Though, in this paper measurement of the size of the cold defect was not performed, but it can be clearly seen that the end-to-end space of cold defect is larger. Thus, it confirms that the effect of scattered gamma photons over the cold defect has been reduced with the use of aluminum material filter.

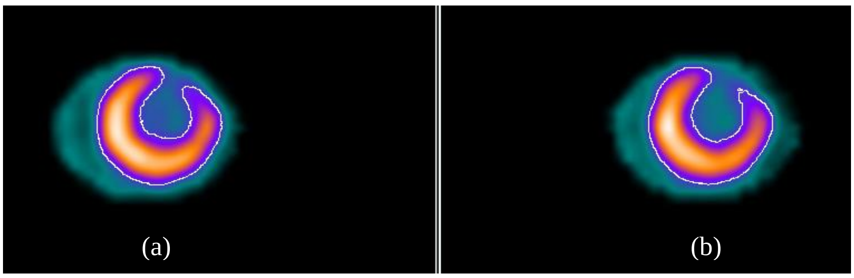

Fig.6: (a) and (b) Show the cold region image of myocardial wall chamber (left ventricle) (a) without and (b) with aluminum 0.1mm material filter

In this study, three different gamma cameras were involved at two different hospitals to show the impact of material filters on the image quality with a view to test the utility of material filter technique. In clinical practice, generally two types of regions are encountered, i.e., hot and cold regions. Effects of scattered gamma photons are different on each type of region. In the case of hot regions, gamma photons scatter outward therefore the appearance of hot region in terms of size is lager as compared to the actual size. On the other hand, cold regions size in the image appears squeezed since scattered gamma photons from the background overlap the cold area.

Hot region and myocardial cold defect analysis with material filters show improvement in image quality relative to the images without material filtered data. Results strongly confirm the usefulness of material filters and evidenced that there is substantial reduction in scattered gamma photons from the raw data of all material filtered images.

IV. CONCLUSION

Findings of the study indicate improvement in parameters such as; perceived image quality of hot regions and their detectability, and the cold defect in the myocardial wall of the left ventricle. The results gathered show that this technique may have important applications in clinical studies.

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