MEDICAL CHANNEL

Original Article

Implementation Of Material Filter Technique For Scatter Correction In TC-99M Planar Imaging Of Thyroid: Phantom Study

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ABSTRACT

Purpose of the Study: Inclusion of scattered gamma photons in nuclear medicine image data degrade the image quality. Number of scatter correction techniques is available unfortunately none of the method is applied in clinical studies. Thus, the objective of this study was to implement the material filter technique to enhance the quality of images in Tc-99m planar imaging of thyroid by removing scattered gamma photons prior to their detection. **Methods**: Picker thyroid phantom was scanned with Philip ADAC Forte gamma camera mounting low energy high resolution collimator. A flat sheet of zinc material (55 x 44 cm^2) of 0.2 mm thickness was placed over the outer surface of the collimator. Tc-99m radionuclide (10mCi) was injected into the phantom. Planar images of the phantom with and without material filter were acquired. Four hundred thousand counts in each image were collected by selecting a 256 x 256 sized matrix. ImageJ software was used to analyze the acquired images. **Results:** Enhancement in image quality of cold and hot regions was attained with the usage of material filter. Significant (p <0.05) reduction in percent root mean square noise (PRMSN) was indicated in the background count density of cold and hot regions with material filter. **Conclusion:** The use of zinc material as a filter could play a significant role in Tc-99m thyroid scintigraphy as high perceived image quality enable qualitative and quantitative information of the organ of interest, lesion features, analysis of shapes and textures to be extracted efficiently and accurately in achieving higher diagnostic accuracy.

KEYWORDS: Material filter, scatter correction, image quality, thyroid nodules

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INTRODUCTION

Nuclear medicine imaging plays a significant role in thyroid scanning for diagnosis of abnormalities. For accurate diagnosis of diseases and quantification of radioactivity concentration in the organ of interest, image quality of the projected organ must be high. The quality of image can be described by contrast, resolution and noise. These parameters are affected by numerous factors; among them are the presence of scattered gamma photons and statistical variations in the counts registered in the image data. The thyroid clinical data accuracy (qualitative and quantitative) is hampered by scattered gamma photons. Thus, perceived image quality and edges of thyroid lobes, cold, warm and hot nodules in the image become "blurred". Therefore, in this situation it is difficult to separate the region of interest (ROI) correctly from its background. Hence accuracy in the diagnosis of disease becomes low. In order to reduce the adverse effects of scattered gamma photons on nuclear medicine images, various scatter correction techniques have been developed by different groups and applied in Tc-99m pertechnetate thyroid imaging and different radioisotopes of iodine, e.g., I-123, I-124 and I-131.[1 – 6] A material filter technique for removal of a fraction of scattered gamma photons prior to their detection by imaging system was applied in positron emission tomography by[7] and in Tc-99m planar[8] and SPECT imaging.[9, 10] Recently, thin flat sheets of Al 0.1, 0.2 and 0.3 mm, Copper 0.125 and 0.127mm as material filters for reduction of scatter in Tc-99m SPECT have been applied.[11-14] It has been reported that material filter reduces some fraction of scattered gamma photons prior to their detection. Therefore, improvement is achieved in the cold and hot regions contrast, detectability and overall image quality. In addition, researchers have suggested the use of filters in Tc-99m SPECT for scanning phantoms which simulate organs of human body.[9-14]

In this work, material filter Zinc (Zn) 0.2 mm thick flat sheet was applied aiming to improve the image quality of thyroid phantom images. The material filter was designed only for Tc-99m radionuclide which is most commonly used radionuclide in single photon emission imaging.

METHODOLOGY

Construction of Material Filter

Type of material and thickness was selected on theoretical calculations considering percent attenuation of various gamma photon energies (ranging from 80 – 200 keV) by different materials using linear attenuation coefficient values, details of which are published in reference.[15] According to the percent attenuation calculations, 0.1mm and 0.2 mm thicknesses of Zn material were found to be suitable for Tc-99m radionuclide imaging. However, material filter was designed from the 0.2 mm thick sheet (55 x 44 cm^2 size) due to non-availability of 0.1 mm thickness. In order to make sure the purity of the Zinc material sheet, Energy Dispersive X-ray (EDX) Spectroscopy was performed. It was found that the material sheet consists of 86.93 weight percent zinc having minor impurities of 7.57 weight percent carbon, 4.39 weight percent oxygen and 1.11 weight percent aluminium.

Image Acquisition

Philip ADAC Forte (dual head) imaging system installed with low energy high resolution (LEHR) collimator was employed. A Picker's thyroid phantom (without neck) consisting of two mirrored lobes having a total volume of 35 cm^3 was used. In terms of the depth of the lobe, the right is deeper as compared to the left lobe. The left lobe has a hot 12 mm and a cold 8.7 mm diameter nodule, whereas, the right lobe consisted of two cold nodules measuring 6 and 12 mm diameter. Technitium-99m radionuclide (10mCi) was injected into the phantom. Symmetrical energy window (20%) centered at 140 keV was selected. The phantom-to-collimator distance was fixed at 10 cm from the face of the collimator. Planar image data was acquired in a 256 x 256 matrix with and without material filter and 400k counts were recorded per image. ImageJ software[16] was used for visual, measuring the contrast of cold and hot regions, contour and overall image quality analysis. For archiving and analysis purpose, thyroid phantom images were saved separately using the GIF format.

Image Analysis

Thyroid images obtained with and without material filter were analyzed qualitatively. ImageJ software was utilized to make a montage of both images (displayed in one window). Effect of material filter

was observed by viewing the edges of thyroid lobes and shapes of the cold and hot regions. Additionally, images were analyzed by plotting line contours. Different contour values were selected in order to show the various count densities in both images. Contour analysis allows easier viewing of edges and shapes of the cold and hot regions precisely. These are shown on each image pointed by arrows of different colors. Use of arrows help to compare contours drawn on both lobes, cold and hot region images which were obtained using material filter and without material filter. Moreover, same colored arrows were drawn for each cold and hot region contour corresponding to the same locality and size with and without material filter in order to make comparison easier. For example, arrows placed on the contour line of cold and hot regions of left lobe with material filter have the same color as the arrows of respective cold and hot region of left lobe without material filter.

Contrast

The cold and hot regions contrast was measured by using Equation (1) and (2), respectively.

$$C_{\text{cold region}} = \frac{D_{reg} - D_{bkg}}{D_{bkg}} \quad (1)$$

where D_{reg} is the average counts in the ROI of cold region, and D_{bkg} is the average counts in the ROI of background.

$$C_{\text{hot region}} = \frac{D_{reg} - D_{bkg}}{D_{reg} + D_{bkg}} \quad (2)$$

where D_{reg} is the average counts in the ROI of hot region and D_{bkg} is the average counts in the ROI of background.

Percent Root Mean Square Noise (PRMSN)

Root mean square noise in the count density is considered as one of the image quality measurement parameter. It is well established that in nuclear medicine imaging, presence of scattered gamma photons are considered as the signals of noise. PRMSN was measured for cold, hot and background regions. Using ImageJ software circular ROIs were drawn according to the size of each cold, hot and background regions and were fitted carefully to avoid overlapping the areas of not interest. Histogram of individual ROI was obtained for recording the average count density and standard deviation in the average count density of each ROI. The equation to measure PRMSN is used as follows:

$$PRMSN = \frac{SD}{D_{mean}} \times 100 \quad (3)$$

where SD is the standard deviation in the mean count density of ROI and D_{mean} is the mean count density in ROI.

Statistical Analysis

Significance difference in percent RMS noise in the count density of cold, hot and the background regions with and without material filter images were calculated by using one-way ANOVA.

RESULTS

Thyroid phantom images obtained without and with

FIGURE 1:
Show planar images of thyroid phantom obtained (a) without and (b) with material filter.

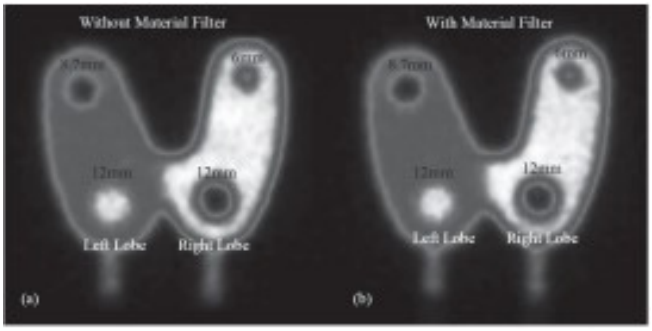


FIGURE 2:
Show contours in planar images of thyroid phantom obtained (a) without and (b) with material filter.

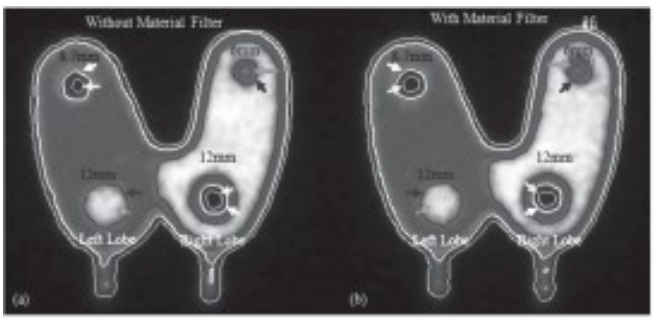


TABLE 1:

Show the percent RMS noise and contrast of cold and hot regions without and with material filter.

Cold/Hot Regions Diameter (mm)	Without Material Filter		With Material Filter	
	Contrast	Percent RMS Nosie	Contrast	Percent RMS Nosie
6 cold	(-) 0.63	16	(-) 0.61	13
8.7 cold	(-) 0.72	25	(-) 0.75	24
12 cold	(-) 0.82	45	(-) 0.82	41
12 hot	(+) 0.31	3.5	(+) 0.31	3.4

TABLE 2:

Show the percent RMS noise values in the count density of background regions in both lobes without and with material filter.

Thyroid Lobe	Without Material Filter	With Material Filter
	Percent RMS Nosie	
Right	7.09	6.57
Left	9.30	8.31

material filter are shown in Figure 1. Visual interpretation of images reflect that, with material filter (Figure 1b) edges of hot and cold regions appear to be smoother as compared to regions without material filter image (Figure 1a). Moreover, uniform background of cold and hot nodules has been observed when compared with that without material filter.

Contour analysis of images shown in Figure 2, the contours on both types of nodules of various diameters pointed by arrows of white and different colours indicate their shape. Viewing carefully the contours over the cold and hot regions image, as shown in Figure 2b (with material filter), shows improvement in the shape i.e., closer shape of cold and hot nodules to the actual (circular) shapes. Additionally, edges of both lobes with the use of material filter are sharper than without material filter (Figure 2a).

In thyroid scintigraphy, accurate quantification of radioactivity distribution or uptake and measurement of precise size, shape of cold and hot nodules in the image is important. The use of material filter improved the shape and perceptibility of the cold and hot regions due to the removal of some fraction of scattered gamma photons before reaching the gamma camera detector. Contrast and percent root mean square noise values of cold and hot regions are presented in Table 1. For 6 and 8.7mm cold regions with material filter, insignificant improvement in contrast was achieved when compared to that without material filter. Further, no improvement in contrast was obtained when material filter was utilized for 12mm cold and hot regions when compared to that without material filter. In this study material filter technique shows improvement in the contrast of smaller cold regions. The other image quality parameter studied was the percent root mean square noise. Results reflect significant reduction ($p<0.05$) in percent RMS noise for 6 and 12 mm diameter cold regions with material filter when compared to without material filter. However, for 8.7mm diameter cold region percent RMS noise was lowered insignificantly with material filter.

Further, for hot region of 12mm diameter percent RMS noise is marginally reduced with the use of material filter. Moreover, significant reduction ($p<0.05$) in the percent RMS noise of background counts of cold and hot regions when material filter was utilized was achieved due to removal of scatter with material

filter as shown in Table 2.

DISCUSSION

In Tc-99m imaging gamma rays scatter in the object can reach to the NaI(Tl) detector of the gamma camera. Since these are low energy gamma rays as compared to un-scattered photons therefore they generate small signals in the detector. However, they may fall within the 20% energy window for Tc-99m. Consequently, events are miss-positioned and registered few centimeters away from their actual site of emission. In terms of the effect on image quality these events contribute to the degradation of image contrast. In addition, the height of pulses produced due to the scattered gamma photons is small as compared to the un-scattered events and appear as the noisy signals in the image.

Theoretically, gamma photons of energy below 150 keV interact with tissue predominantly via coherent scattering. In this interaction mechanism, gamma photons scattering angle is very small, therefore, they are not discriminated from un-scattered photons by the pulse height analyzer and are registered in the photo peak energy window. Another kind of interaction of gamma photons is Compton scattering, where some fraction of incident gamma photon energy is given off to the interacting medium. The loss of energy depends upon the scattering angle. Even larger angle deflection causes small loss of energy, therefore, gamma photons scattered at 90^{o} angle are still detected in the 20% energy window. Thus, Compton scattering has been given much emphasis in single photon emission imaging in terms of image data correction. Additionally, in Tc-99m single photon emission imaging multiple scattering also takes place. The presence of multiple scattered gamma photons has been reported by[17]. About 20% multiple scattered gamma photons of total scatter in a symmetrical standard energy window centered at 140 keV are present.

In nuclear medicine, it is always desirable to obtain good quality images and accurate quantitative information for better diagnostic and treatment services to the patients. Furthermore, in order to achieve higher diagnostic accuracy, perceived image quality must be high in enabling extraction of the qualitative and quantitative information of the organ of interest, organ lesion features, analysis of shapes and textures efficiently and accurately.

Thyroid scintigraphy either by using radioisotopes of iodine (I-123, I-124 and I-131) or Tc-99m radionuclide is considered as an excellent tool for evaluation of thyroid functioning in routine clinical studies. However, it has limitations in estimating the accurate thyroid volume and measuring the size of thyroid nodules (cold, warm and hot) as unfortunately, edges of nuclear medicine images of thyroid are unclear and blurry due to the presence of high percentage of noise in the image. Measurement of precise thyroid volume and nodule size has significant impact in achieving the accurate diagnosis of disease and on therapeutic procedures. Accurate volume of thyroid, features, shape and texture of thyroid lobes and size can only be determined by precise corrections, for instance the removal of scattered gamma photons. Precise separation of region of interest from the background plays a vital role in the estimation of correct thyroid volume, nodule size determination and quantification of radioactivity concentration for which the boundaries of regions of interest should be clear. Generally, image thresholding and segmentation algorithms are used for delineation of different regions of interest in the image.[18,19] Nonetheless, these algorithms work well only when image quality is good. Moreover, in the clinical setting, regions of interest on the lesion are manually drawn by clinicians which makes it a subjective task and can vary from person to person, therefore, chances for errors in the diagnosis of the disease and quantification of radioactivity uptake are high. In this study, the material filter technique improved the shape and detectability of hot and cold regions. Relevance in the results of this work have been reported by[11,13] in which physical filters constructed from various types of materials were applied. Thus, the use of material filter is proven to be good for delineation of the thyroid lobes from the background activity and may make analysis of images easier, both visually and quantitatively. Thereby aiding in estimating the correct volume of thyroid as well as quantifying the sizes of cold, warm and hot nodules in Tc-99m single photon emission imaging. Therefore, clinically useful results may be achieved due to better management of thyroid patients as a result of accurate diagnosis.

It is well established that in nuclear medicine imaging small regions (cold/hot) are most affected by the scattered gamma photons that travel from their background regions. On the other hand, only edges of larger regions are overlapped.[20] In clinical examinations, detection of smaller regions has always remained a serious issue, hence requires much attention. Our study shows that material filter has improved cold and hot regions contrast. Results of this study are in line with the work done by.[11,13,14, 20] However, there is significant reduction in the percent RMS noise with material filter. Which shows that material filter absorbs scattered gamma photons (single + multiple) before they reach to the detector of the gamma camera. In terms of clinical investigations a smaller change in the image quality might have a significant impact in terms of the accuracy of the diagnosis of the disease. Therefore, results of this work suggest the utility of zinc (0.2 mm) material filter in Tc-99m single photon emission imaging.

CONCLUSION

Extraction of clinically useful information from poor quality images pose challenges to the nuclear medicine practitioners. Results show that the material filter technique may prove to be useful in clinical studies to improve diagnostic confidence. However, findings of this work may require additional studies using other types of thyroid phantoms as well as further clinical trials on human population. This study was limited to the fact that data was collected using a phantom without the neck and therefore might not mimic that of a human anatomy.

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