Evaluation of external beam hardening filters on image quality of computed tomography and single photon emission computed tomography/computed tomography

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ABSTRACT

This study was undertaken to evaluate the effect of external metal filters on the image quality of computed tomography (CT) and single photon emission computed tomography (SPECT)/CT images. Images of Jaszack phantom filled with water and containing iodine contrast filled syringes were acquired using CT (120 kV, 2.5 mA) component of SPECT/CT system, ensuring fixation of filter on X-ray collimator. Different thickness of filters of Al and Cu (1 mm, 2 mm, 3 mm, and 4 mm) and filter combinations Cu 1 mm, Cu 2 mm, Cu 3 mm each in combination with Al (1 mm, 2 mm, 3 mm, and 4 mm), respectively, were used. All image sets were visually analyzed for streak artifacts and contrast to noise ratio (CNR) was derived. Similar acquisition was done using Philips CT quality control (QC) phantom and CNR were calculated for its lexan, perspex, and teflon inserts. Attenuation corrected SPECT/CT images of Jaszack phantom filled with 444–555 MBq (12–15 mCi) of ^{99m}Tc were obtained by applying attenuation correction map generated by hardened X-ray beam for different filter combination, on SPECT data. Uniformity, root mean square (rms) and contrast were calculated in all image sets. Less streak artifacts at iodine water interface were observed in images acquired using external filters as compared to those without a filter. CNR for syringes, spheres, and inserts of Philips CT QC phantom was almost similar to Al 2 mm, Al 3 mm, and without the use of filters. CNR decreased with increasing copper thickness and other filter combinations. Uniformity and rms were lower, and value of contrast was higher for SPECT/CT images when CT was acquired with Al 2 mm and 3 mm filter than for images acquired without a filter. The study suggests that for Infinia Hawkeye 4, SPECT/CT system, Al 2 mm, and 3 mm are the optimum filters for improving image quality of SPECT/CT images of Jaszack or Philips CT QC phantom keeping other parameters of CT constant.

Key words: Artifacts, attenuation correction, filters, image quality

Introduction

Single photon emission computed tomography (SPECT) imaging involves the acquisition of various planar projections at equally spaced angular intervals around the patient or material being imaged.[1] The purpose of SPECT imaging is a precise three-dimensional localization of the activity distribution inside the body. There are various physical factors that affect the distribution of photons in SPECT study such as attenuation and scattering.[2] Attenuation of photons is considered as the most affecting physical factor in quantitative accuracy and interpretation of SPECT data.[3]

Various methods have been employed for correction of attenuation in SPECT data.[4] Attenuation is an exponential physical phenomenon which is dependent on the density and atomic number of material. It is characteristic for each

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material and represents the probability of interaction per unit path length. It is typically represented by the symbol "μ" and expressed in the unit of cm^{-1}.[3]

Since it is characteristic for each material, correction of attenuation requires knowledge of the distribution of attenuation coefficient in the material. The additional information required for correction of attenuation data of SPECT can be obtained using transmission sources like external radionuclide source (Gd 153 with a 100 keV photon and Tc 99 m with a 140 keV photon) or X-rays.[4,5] Higher photon flux of X-ray makes it the method of choice for better resolution. Moreover, scan time is also less with the use of X-rays as attenuation correction method.[6] Thus, hybrid SPECT/computed tomography (CT) having multidetector SPECT coupled with conventional CT in a single gantry allows robust attenuation correction, with the help of algorithms developed for attenuation correction using CT data.[7]

Generation of attenuation correction maps for SPECT data is done by conversion of CT data present in HU units to attenuation coefficients by various conversion methods.[6] X-rays have a continuous spectrum of energy, ranging in keV from 0 to a max of kVp used to generate the image. The CT data generated is for the average energy of the X-ray photons which is approximately one-third of the maximum kVp used.[8] The average energy of X-ray beam can be increased either by increasing voltage applied for generation of X-ray beam or by application of external filters to absorb lower energy component of the X-ray beam. Absorption of the lower energy component of X-ray beam results in hardening of the beam and hence greater penetration due to increased average energy.

In the absence of external filters, the low energy photon component is absorbed in the tissue resulting in beam hardening and increased patient dose. Thus, passage of the beam through tissue results in a shift of beam spectrum toward higher energy and thereby changes effective attenuation coefficient since attenuation depends upon the energy of the photon.[9]

Added filtration using metals such as copper and aluminum can be used to enrich the beam with higher-energy photons by absorbing the lower-energy components of the spectrum resulting in hardening of the beam and hence greater penetrating power. Use of such beam for transmission scans results in the calculation of corrected attenuation coefficients, which can then be applied to SPECT data. In addition, effect of corrected attenuation maps on SPECT images can be seen using different parameters as proposed earlier.[10]

The present study focuses on optimizing a filter for beam hardening and application of corrected attenuation maps on SPECT data to look for improvement in image quality parameters after application of corrected attenuation maps.

Materials and Methods

This study was done using Jaszack Phantom [Figure 1a] and Philips CT quality control (QC) phantom having six different density inserts of polyethylene, teflon, perspex (acrylic), lexan, nylon (aculon), and water [Figure 1b]. Data were acquired on a dual-headed SPECT/CT system (Infinia Hawkeye 4, GE Healthcare Waukesha, Wisconsin, USA) with low-dose multiple detector CT (4-slice). CT specifications as mentioned in Table 1. External filters of two different materials having different Z value (Cu, Al) with different thicknesses (4, 3, 2, and 1 mm) with dimensions so as to exactly fit on the collimator cover of CT X-ray tube were used.

Acquisition

Jaszack phantom was filled with water without any radioactivity since initially the concern was only hardening of the X-ray beam. In addition, 2–3 iodine contrast (300 mgI/ml) filled syringes with lumen diameter of 10 mm and cross section area of 78.5 mm^2 were placed in Jaszack phantom to see effect of heterogeneity on the image surfaces. Post daily QC, CT acquisition of phantom was started after ensuring appropriate fixation of filter material on collimator cover. CT acquisition parameters were helical scan type with pitch: 1.9, slice thickness: 5 mm using tube current: 2.5 mA, and tube voltage: 140 kV with rotation velocity: 2.5 RPM and CT image was reconstructed in 512 × 512 matrix size using standard filter. Following filters and filter combination were used: Al ranging from 1 to 4 mm abbreviated as Al1, Al2, Al3, and Al4, respectively, Cu ranging from 1 to 4 mm abbreviated as Cu1, Cu2, Cu3, and Cu4, respectively, and Cu 1 mm in combination with each Al 1 mm, Al 2 mm, Al 3 mm, and Al 4 mm abbreviated as Cu1Al1, Cu1Al2, Cu1Al3, and Cu1Al4, respectively; Cu 2 mm in combination with each Al 1 mm,

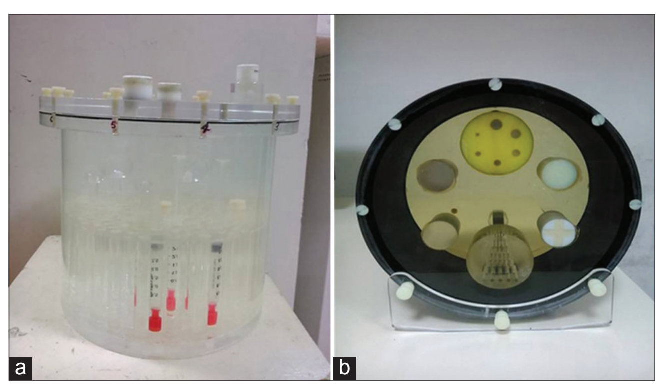

Figure 1: (a) Jaszack phantom with iodine contrast filled syringes (b) Philips computed tomography quality control phantom having six different density inserts of polyethylene, teflon, perspex (acrylic), lexan, nylon (aculon), and water

Al 2 mm, Al 3 mm, and Al 4 mm abbreviated as Cu2Al1, Cu2Al2, Cu2Al3, and Cu2Al4, respectively; Cu 3 mm in combination with each Al 1 mm, Al 2 mm, Al 3 mm, and Al 4 mm abbreviated as Cu3Al1, Cu3Al2, Cu3Al3, and Cu3Al4, respectively. Combination filters were placed with higher atomic number filter (Cu), facing X-ray tube followed by lower atomic number filter (Al).[8] Recalibration of CT system was done every time with a respective filter before scanning the phantom. A set of images without any external filter were also acquired abbreviated as no filter (NF). Similar acquisition was done for Philips CT QC phantom.

To see the effect of application of external filters on SPECT data, Jaszack phantom was filled with 444–555 MBq (12–15 mCi) of Tc-99 m sodium pertechnetate. Uniform distribution of activity was ensured with the proper shaking of the phantom before filling it completely. SPECT study was acquired in 128 × 128 matrixes with 120 views with a sampling of 3° all over 360° followed by CT acquisition of Jaszack phantom for generation of attenuation correction maps for SPECT data. For the first study, CT acquisition was done with no external filter. SPECT/CT studies were then done for the same phantom, with CT acquisition done using different filter, and filter combinations (Al1, Al2, Al3, Al4, Cu1, Cu2, Cu3, Cu4, Cu1Al1, Cu1Al2, Cu1Al3, Cu2Al1, Cu2Al2, Cu2Al3, Cu3Al1, Cu3Al2, and Cu3Al3) as mentioned above. A total no of counts acquired for all SPECT/CT studies were kept almost similar (~27M to 30M), by changing acquisition time per view according to the count rate. CT acquisition generated attenuation correction map for attenuation correction of SPECT data of Jaszack phantom corresponding to hardened X-ray beam produced by each filter and filter combinations. Attenuation-corrected SPECT/CT images were obtained by applying attenuation correction map generated by hardened X-ray beam with different filters and filter combinations and also for no filter, on SPECT data. SPECT images were reconstructed using iterative reconstruction algorithm (ordered subsets expectation maximization) with 10 subsets and two iterations and Hann filter with 0.9 cut-off.

Data analysis

All acquired image data sets were displayed using Xeleris 2 workstation (GE Healthcare) and were visually analyzed to look for streak artifacts due to high-low density interfaces (iodine and water) in case of Jaszack phantom. Contrast to noise ratio (CNR)[11] for iodine syringes and for a largest cold sphere (31.8 mm) were calculated for all image sets. For Philips CT QC phantom, CNR for lexan, perspex, and teflon inserts was calculated.

$$\text{Contrast to Noise Ratio (CNR)} = \frac{\text{CT no.of object} - \text{CT no.of background}}{\text{Standard Deviation of CT no.of background}}$$

Different image quality parameters such as uniformity, root mean square (rms) value, and contrast[12] were computed for each data set of SPECT/CT images, obtained by external filter and that without any external filter. Parameters were then compared and studied for change in different image sets.

$$\text{Uniformity} = \frac{\text{Max. pixel counts} - \text{Min. pixel counts}}{\text{Max. pixel counts} + \text{Min. pixel counts}}$$

$$\text{Root mean square(rms)} = \frac{\text{Standard deviation}}{\text{Mean pixel value}}$$

$$\text{Contrast} = \frac{\text{Average counts of uniform slice} - \text{Min. counts in coolest pixel}}{\text{Average counts of uniform slice}}$$

For calculation of uniformity and rms all image sets of SPECT/CT images were scrolled for an uniform slice and then five rectangular regions of interests (ROIs) (~4500 pixel area) were deposited each at center, right, left, upper, and lower side of the uniform section and values for minimum, maximum, mean pixel counts, and standard deviation were noted for each ROI [Figure 2a]. The average of these values over five ROIs was then used for calculation of uniformity. In the calculation

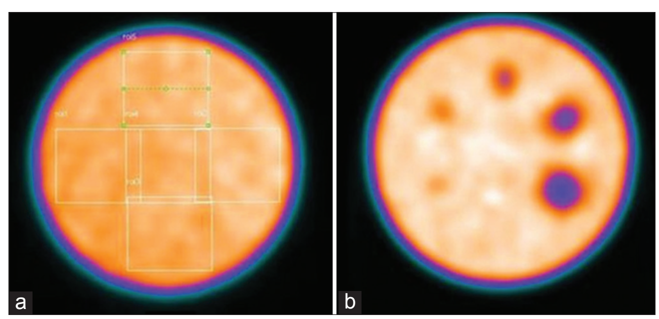

Figure 2: Cross section of Jaszack phantom (a) of uniform slice showing regions of interest's placed at five different positions for calculation of average counts (b) showing cold spheres

Table 1: CT specifications for SPECT/CT system

Scan mode	*Reconstruction filter*	*Detector pitch at isocenter*	*Slice width*	*Tube voltage (kV)*	*Tube current*	*Tube/ rotation (s)*	*mAs*
Axial half	Standard	1.19 mm	5 mm	120, 140	1-2.5 mA	14	14.0-35.0
Axial full	Soft					23	23.0-57.5
Helical (pitch=1.923 cm)	Bone					23	12.0-30.0

SPECT: Single photon emission computed tomography, CT: Computed tomography of rms, "standard deviation" mentioned in the equation is the average value of "standard deviations of the counts in each ROI," averaged over five ROIs mentioned above. Similarly, "mean pixel value" mentioned in the equation of rms is the average value of the "mean value of counts in each ROI," averaged over five ROIs mentioned above.

The calculation of contrast, used two different slices, one was a uniform slice for calculation of "average counts of uniform slice" [Figure 2a] and second slice used was that containing cold spheres for calculation of "minimum counts in coolest pixel" [Figure 2b]. Uniform slice used was the same slice as mentioned above having five ROIs placed at the center, left, right, upper, and lower side of the uniform section. The average of "mean values of counts" in each ROI, averaged over five ROIs was used as "average counts of uniform section" in the calculation of contrast. In the slice containing cold spheres, minimum counts in sphere was noted by drawing circular ROI inside the largest visible cold sphere to be used as "minimum counts in coolest pixel" in the calculation of contrast.

Results

Qualitative analysis for all image sets was done in the case of Jaszack phantom without activity. For all image sets, cross section showing iodine filled syringes were analyzed to look for streak artifacts due to iodine water interface contrast. It was observed that less streak artifacts were seen in image sets acquired with filters in comparison to image set acquired without any external filter [Figures 3-7].

For quantification, CNR value averaged over two or three iodine filled syringes, and the largest cold sphere (31.8 mm) is shown in Table 2. In addition, the variation of CNR value with different filter thicknesses and filter combination for iodine syringes and sphere can be seen in Figure 8a and b, respectively.

It was seen that the value of CNR was almost similar for images acquired without any external filter and for those acquired with Al 2 mm or Al 3 mm. The value was found to be decreasing with increasing copper thickness and then again increased for filters used in combination for Cu 1 mm filter in combination with Al 1 mm filter and then the value gradually decreased for other combinations.

Similar trend for CNR value for lexan, perspex, and teflon insert of Philips CT QC phantom was observed as can be seen in Figure 8c and d. Image cross section for Philips CT QC phantom can be seen in Figure 9.

Quantitative analysis was done to see for improvement in image quality of SPECT/CT images of Jaszack phantom filled with activity, obtained by application of different filters, and filter combination. Uniformity was found to be lowest,

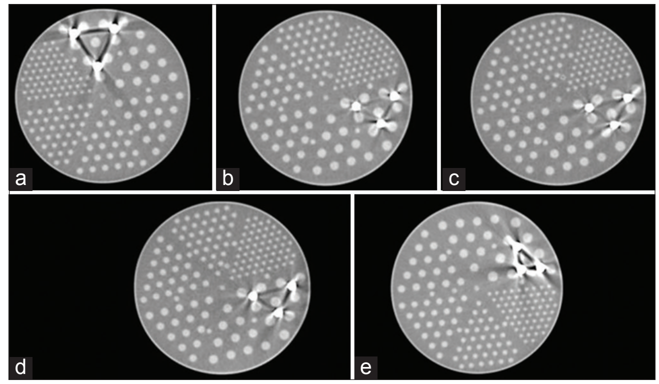

Figure 3: Cross section of Jaszack phantom without activity showing streak artifacts due to iodine water interface contrast in computed tomography acquisition with (a) no filter (b) Al 1 mm (c) Al 2 mm (d) Al 3 mm (e) Al 4 mm filter while computed tomography acquisition

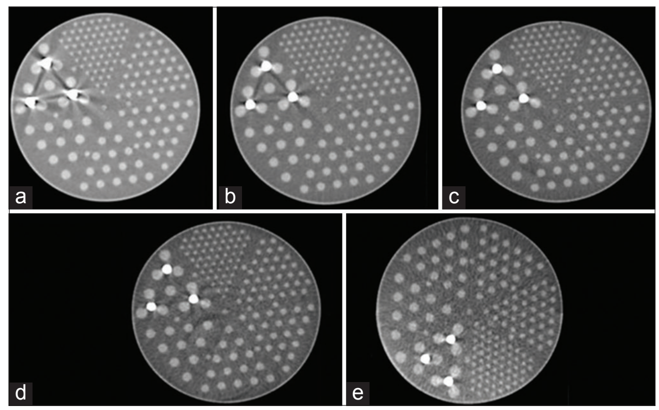

Figure 4: Cross section of Jaszack phantom without activity showing streak artifacts due to iodine water interface contrast in computed tomography acquisition with (a) no filter (b) Cu 1 mm (c) Cu 2 mm (d) Cu 3 mm (e) Cu 4 mm filter while computed tomography acquisition

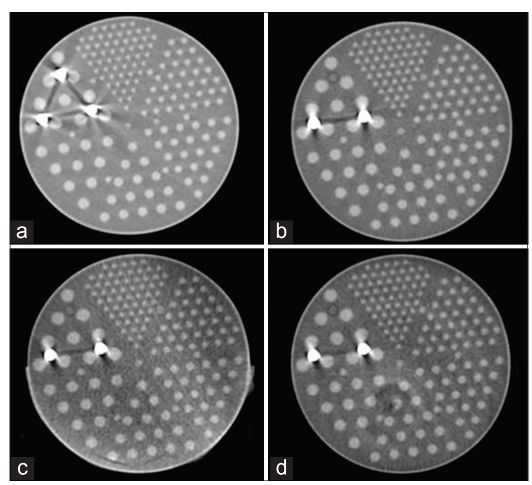

Figure 5: Cross section of Jaszack phantom without activity showing streak artifacts due to iodine water interface contrast in computed tomography acquisition with (a) no filter (b) Cu 1 mm + Al 1 mm (Cu1Al1) (c) Cu 1 mm + Al 2 mm (Cu1Al2) (d) Cu 1 mm + Al 3 mm (Cu1Al3) while computed tomography acquisition

that is, 4.53% for Al 2 mm filter which was comparable with uniformity calculated using Al 3 mm filter, that is, 4.64%.

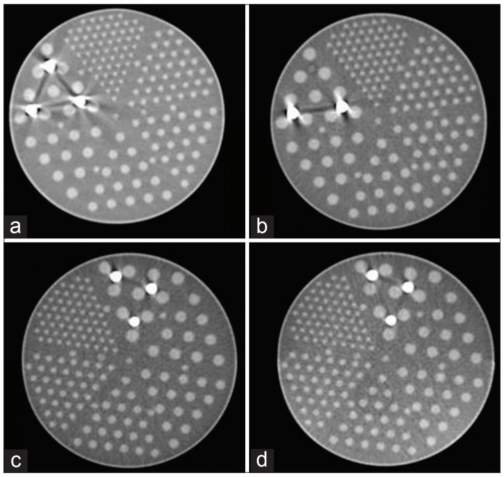

Figure 6: Cross section of Jaszack phantom without activity showing streak artifacts due to iodine water interface contrast in computed tomography acquisition with (a) no filter (b) Cu 2 mm + Al 1 mm (Cu2Al1) (c) Cu 2 mm + Al 2 mm (Cu2Al2) (d) Cu 2 mm + Al 3 mm (Cu2Al3) while computed tomography acquisition

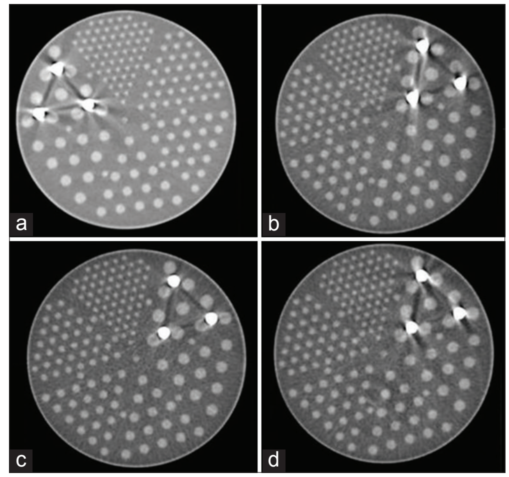

Figure 7: Cross section of Jaszack phantom without activity showing streak artifacts due to iodine water interface contrast in computed tomography acquisition with (a) no filter (b) Cu 3 mm + Al 1 mm (Cu3Al1) (c) Cu 3 mm + Al 2 mm (Cu3Al2) (d) Cu 3 mm + Al 3 mm (Cu3Al3) while computed tomography acquisition

Table 2: CNR value for iodine contrast filled syringes, cold sphere of Jaszack phantom without activity and for teflon, lexan, and perspex insert of Philips CT QC phantom for NF and different filter thicknesses and filter combinations

Filter and filter combination	*CNR*				
	Iodine contrast syringes (average)	*Sphere*	*Perspex*	*Lexan*	*Teflon*
NF	178.3018	7.753741	9.1668	8.539	59.6831
Al1	176.7372	7.685277	9.195	8.278	58.005
Al2	155.9223	6.688915	8.406	7.79	55.1079
Al3	160.2284	6.964243	8.227	7.636	53.8446
Al4	156.573	6.935504	7.639	7.081	49.73356
Cu1	115.9802	5.086659	5.7074	5.256237	36.0482
Cu2	82.63578	3.811709	3.975246	3.55592	24.49866
Cu3	59.12678	2.851243	2.907194	2.697602	17.9627
Cu4	46.37824	2.448819	2.706631	2.449958	16.6128
Cu1Al1	105.6963	4.770476	5.553645	5.009828	34.78501
Cu1Al2	110.3638	4.996154	5.722735	5.296141	35.60277
Cu1Al3	98.04647	4.430801	4.861251	4.450395	30.30661
Cu1Al4	102.0376	4.600703	4.667931	4.295862	29.15069
Cu2Al1	77.31352	3.554444	4.40384	4.002021	27.55709
Cu2Al2	72.98394	3.324611	4.086673	3.83411	25.55048
Cu2Al3	78.1108	3.588284	3.8692	3.551624	23.78277
Cu2Al4	69.71371	3.24796	3.439678	3.141287	21.82547
Cu3Al1	62.51252	3.064478	3.261645	2.889742	20.03072
Cu3Al2	56.85013	2.809555	3.237944	2.939535	19.68984
Cu3Al3	56.88874	2.730395	3.444298	3.152128	21.07803
Cu3Al4	71.21323	2.795706	3.402778	3.014646	20.38838

CNR: Contrast to noise ratio, NF: No filter, CNR: Contrast to noise ratio, CT: Computed tomography, QC: Quality control

However, both these values were better than that obtained for SPECT/CT images acquired without any filter and for the image with any other filter combination. The value of uniformity increased with increase in thicknesses of Cu filter. For other filter combinations, maximum value of uniformity, that is, 7.8% was found for images with combination filter of Cu 2 mm with Al 3 mm (Cu2Al3) followed by 6.28% for Cu2Al2 and minimum value of 4.9% for images acquired with Cu3Al3. The values of uniformity obtained for images with combination filters Cu1Al1, Cu1Al3, and Cu3Al3 were better than obtained for Cu 2 mm, Cu 3 mm, and Cu 4 mm. Another quantitative parameter calculated for all image sets of SPECT/CT was rms. Rms value showed a similar trend in values as was seen for uniformity, the smallest value being 1.8% for Al 2 mm followed by 1.9% for Al 3 mm. These values were, however, lower than that

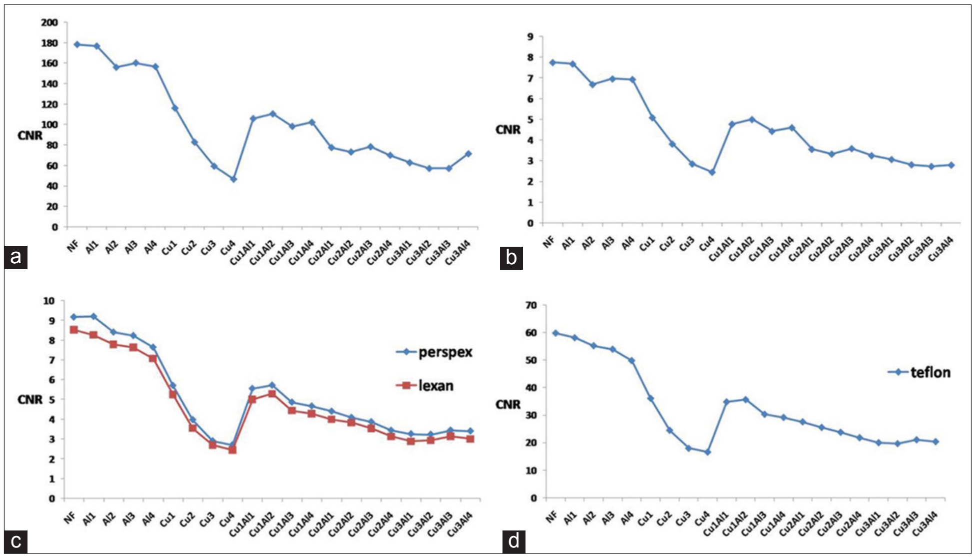

Figure 8: Variation of CNR value with different filter thickness and filter combinations (a) for iodine filled syringes (b) sphere of Jaszack phantom without activity (c) lexan and perspex inserts of Philips computed tomography quality control phantom (d) teflon insert of Philips computed tomography quality control phantom

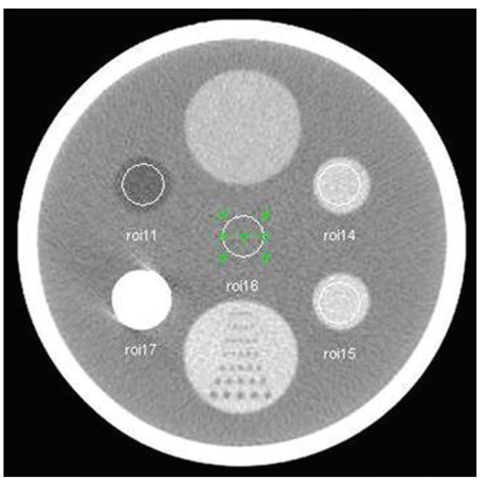

Figure 9: Cross section of Philips computed tomography quality control phantom

for image sets acquired without any filter, that is, 2.22%. For combination filter maximum value of rms, that is, 2.95% was again found for (Cu2Al3) followed by 2.65% for Cu2Al2 and a minimum value of 4.9% for images acquired with Cu3Al3. The values of rms obtained for images with combination filters Cu1Al1, Cu1Al3, Cu2Al1, and Cu3Al3 were better than obtained for Cu 2 mm, Cu 3 mm, and Cu 4 mm. The contrast was also calculated for these image sets. Contrast calculated for cold sphere had a maximum value of 4.69 for images acquired with Al 3 mm filter followed by 4.5 for Al 2 mm. These values were higher than that for images acquired without any external filter. Contrast values for images acquired with combination filters were lower than aluminum filter or for no filter with a minimum value of 0.27 for Cu2Al3. The maximum value of contrast for images acquired with combination filters was obtained for Cu1Al2, that is, 0.41 which was same for images acquired with Cu 2 mm. Contrast values obtained for Cu1Al1, Cu1Al2, Cu1Al3, Cu2Al1, and Cu3Al1 were comparable to values obtained for images with Cu filters. However, the values of contrast for other combination filters were less than that obtained for Cu filters. The value of uniformity, rms, and contrast for all the image sets acquired with different filters, filter combination, and without filter (NF) can be seen in Table 3. In addition, the variation of each parameter uniformity, rms, and contrast with different filters, filter combination and without filter (NF) can be seen in Figure 10a-c, respectively.

Discussion

In CT acquisition, either as a stand-alone modality or as hybrid modality as SPECT/CT, effect of beam hardening on image quality needs to be evaluated, since X-rays have continuous spectrum with lower energy component being easily absorbed by soft tissue leading to increase in patient dose and degradation of image quality. As per Goldman *et al*. the most common type of shading effect present on any type of CT image is due to beam hardening.[13] Kinahan *et al*. in their study on PET imaging stated that in X-ray based attenuation correction, the role of beam hardening cannot be overlooked.[6]

Beam hardening and hence patient dose and image degradation can be reduced by application of external filters and is also taken care by reconstruction algorithm to some extent.[13]

Most CT scanners are equipped with inbuilt bowtie filters to minimize radiation dose in thinner portion of patient's anatomy and thus reducing variation in intensity across detection element.[14] In our study, the effect of application

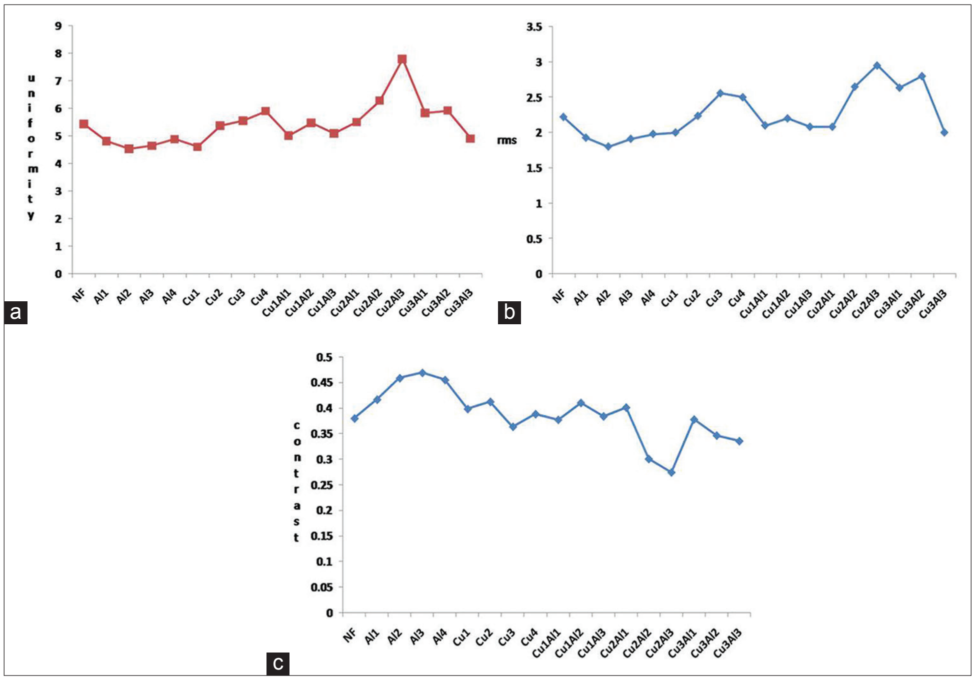

Figure 10: Variation of (a) uniformity (b) root mean square (c) contrast for cold sphere, of single photon emission computed tomography/computed tomography images of Jaszack phantom corrected with X-ray beam using different filter thickness and filter combinations

Table 3: Value of (a) uniformity (b) rms (c) contrast for cold sphere, of SPECT/CT images of Jaszack phantom corrected with X-ray beam using different filter thickness and filter combinations

Filter and filter combination	*Uniformity*	*rms*	*Contrast*
NF	5.43	2.22	0.3796
Al1	4.81	1.926	0.4164
Al2	4.525	1.8	0.4585
Al3	4.642	1.91	0.469
Al4	4.88	1.98	0.455
Cu1	4.6	2	0.398
Cu2	5.37	2.236	0.412167
Cu3	5.547	2.557	0.36325
Cu4	5.9	2.5	0.388
Cu1Al1	5.01	2.1	0.377
Cu1Al2	5.47	2.2	0.41
Cu1Al3	5.09	2.08	0.3837
Cu2Al1	5.5	2.08	0.401
Cu2Al2	6.28	2.65	0.3
Cu2Al3	7.8	2.95	0.2736
Cu3Al1	5.835	2.635	0.3775
Cu3Al2	5.92	2.8	0.346
Cu3Al3	4.9	2	0.335

rms: Root mean square, NF: No filter, SPECT: Single photon emission computed tomography, CT: Computed tomography

of external filters on image quality was seen for CT as well as for SPECT/CT images in the presence of scanner's inbuilt filters (if present).

In this study, when the effect of filters was seen on CT images of Jaszack phantom, it was found that with the application of filters, streak artifacts were reduced which further decreased with increase in the thickness of filters. This could be explained by absorption of lower energy photons. CNR values were almost similar for no filter applied, or with the application of Al 1 mm, Al 2 mm, or Al 3 mm filter and the values decreased thereafter for other filters and filter combination as compared to CNR value for images without any filter. Combining both qualitative and quantitative analysis it can be concluded that application of aluminum filter produced better CT image in comparison to images acquired without any additional filter (copper and other combination filters), though we could not zero down to optimum thickness of aluminum filter.

In a similar study, Cu 3 mm filter was found to be optimal for removing the artifacts and degradation in the image quality was noticed with further increase in filter thickness to 4 and 5 mm.[10] In this study, though steak artifacts were better removed with application of copper filter and combination filters in comparison to aluminum filters, but overall quality of images were poor for copper filter as compared to aluminum filters. This can be attributed to decrease in photon flux due to increased filter thickness. In addition, the value of the quantitative parameter, CNR was found to be better for images acquired with aluminum filters. However, Kheruka *et al*. did not study the effect of aluminum filters and combination filters on beam hardening.[10]

Another study by Ay *et al*. aimed at finding optimum external filter thickness to reduce patient dose and improvement of image quality, concluded that with an additional filter of 0.5 mm Cu or minimum 4 mm Al, a good compromise between image quality and patient dose is achieved for CT images acquired at tube current 200 mA and tube voltages of 120 and 140 kVp.[15] However, CT parameters in two studies were different, 200 mA of tube current used in their study as compared to 2.5 mA used in the present study. Since X-ray intensity or photon flux is directly proportional to tube current.[16] The intensity of X-ray beam in our study was very low which will result in an increase in inherent noise due to less statistical counts, so comparison of results for these two studies is not justified.

After studying the effect of filtered X-ray beam on CT images. The effect of filtered X-ray beam on the generation of attenuation correction maps for SPECT data was studied. Uniformity is an important image quality parameter for SPECT data, since presence of even very small nonuniformities can produce artifacts in SPECT images which can be very misleading,[17] and so is considered most sensitive parameter to change in system performance.[18] Another parameter, rms estimates the noise present in the study.[19] For comparison purposes, we have assumed images with lower rms value to be better than those having higher rms value, since lower the rms value lower will be the noise and hence better will be the image quality and also since trend for rms and uniformity values in our study was similar, same assumption was made while comparing uniformity values. In this study, uniformity and rms values were found to be lower and hence better for SPECT/CT images acquired with Al 2 mm and Al 3 mm filter than for images acquired without any filter. The contrast of cold sphere is also an important parameter for the analysis of image quality of SPECT imaging,[20] higher the contrast, better the image quality. In this study, the contrast was found to be higher for image sets acquired with Al 3 mm and Al 2 mm than for images acquired without any external filter.

So, considering all three parameters, that is, uniformity, rms, and contrast, it can be concluded that application of either Al 2 mm or Al 3 mm filter to generate attenuation correction maps for SPECT data resulted in better images in comparison to images obtained using attenuation correction map generated by unfiltered X-ray beam or any other filter or filter combination.

The effect of beam hardening using filters on attenuation correction maps of SPECT data has not been assessed in any study so far to the best of our knowledge.

Conclusion

Application of external filters removed streak artifacts in CT images. In the present study, application of aluminum filter produced better CT images in comparison to images acquired without any additional filter, copper filter, and other combination filters. Also, beam hardening of X-ray beam effects the generation of attenuation correction maps for SPECT data and this can be corrected by prehardening of X-ray beam using external filters and thus reducing unnecessary patient dose and image degradation. In conclusion, for Infinia Hawkeye 4 SPECT/CT system, Al 2 mm, and Al 3 mm appear to be optimum filter for improving image quality of SPECT/CT images using Jaszack and Philips CT QC phantom keeping other parameters of CT constant.

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Conflicts of interest

There are no conflicts of interest.

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