The Influence of X-ray Spectra Filtration on Image Quality and Patient Dose in the GE VCT 64-Slice Cardiac CT Scanner

M. R. Ay and A. Ahmadian
Dept. Medical Physics and Biomedical Engineering &
Research Center for Science and Technology in Medicine &
Research Institute for Nuclear Medicine, Tehran University of
Medical Sciences, Tehran, Iran
mohammadreza_ay@tums.ac.ir

A. Maleki
Faculty of Physics and Nuclear Engineering,
Amir Kabir University of Technology
Tehran, Iran

H. Ghadiri
Department of Medical Physics
Iran University of Medical Sciences
Tehran, Iran

P. Ghafarian
Department of Radiation Medicine
Shahid Beheshti University
Tehran, Iran

H. Zaidi
Division of Nuclear Medicine
Geneva University Hospital
Geneva, Switzerland
habib.zaidi@hcuge.ch

Abstract – **The polyenergetic x-ray spectra used during CT imaging makes it subject to beam hardening artefacts caused by the absorption of low energy x-rays as they pass through the patient. The direct consequence is that the linear attenuation coefficient calculated for thick body regions is lower than in thin regions. This effect generates cupping and streak artefacts in the reconstructed CT images thus compromising their use in clinical diagnosis. A possible solution for reduction of beam hardening artefact and furthermore minimizing patient dose is, to use suitable x-ray spectra filtration of aluminium (Al) or cupper (Cu) before penetration of the x-ray photons into the patient's body. In this study, we quantified the effect of using different x-ray spectra filtration on image quality, patient dose and modulation transfer function (MTF) in the GE LightSpeed VCT 64-slice cardiac CT scanner using experimental measurements. Different thicknesses of Cu filters ranging from 0.13 to 1.6 mm were installed on the collimator aperture. A cylindrical phantom comprising 16 different materials for modelling of different tissues and the GE performance phantom were scanned at different tube voltages and thicknesses of Cu filters. The absorbed dose in the centre of the phantom was measured using a pencil dosimeter placed in the central part of the phantom. Then the images acquired using different filters were analyzed through comparison of the CT numbers (contrast) and standard deviation (noise) of different ROIs in the phantom with the values obtained using the default filtration of the scanner fixed in the factory. To assess the influence of x-ray spectra filtration on MTF, the GE performance phantom was used. The additional filtration of 0.6 mm Cu was considered as the optimal filter resulting in acceptable image quality with minimum dose (50% reduction). This study is being continued by employing different filter thicknesses to accurately find the optimum filtration required for the GE VCT scanner to achieve the best image quality with the least possible patient absorbed dose.**

Keywords- CT; Scatter; Filter; MTF; Dose; Image Quality

I. INTRODUCTION

Recent developments in computed tomography (CT) allow reduced scan times, faster rotation speed and thinner slices leading to higher image quality. Moreover, recent developments in x-ray tube design allow to lower patient dose. The effective dose exposure of a typical CT examination is now between 1 and 20 mSv depending on the scan length and scan region. Doses delivered to patients undergoing CT examinations are relatively high in comparison with radiation doses associated with other types of diagnostic radiological procedures. There is a growing concern that radiation doses delivered to patients during CT examinations can result in real radiation risks. Many techniques were proposed for reduction of patient dose. Among them, one the most efficient ways consists in using additional aluminum or cupper filters to eliminate the low energy photons in the x-ray spectrum. Although this method can effectively decrease patient dose, it also increases the noise in the reconstructed images in some cases. Therefore optimization of filter thickness to decrease patient dose, while keeping the noise to acceptable levels in the reconstructed images is an active research area. Moreover, the polyenergetic x-ray spectra used during CT imaging makes it subject to beam hardening artefacts caused by the absorption of low energy x-rays as they pass through the patient's body. The direct consequence is that the linear attenuation coefficient calculated for thick body regions is lower than thin regions [1]. This effect generates cupping and streak artefacts in the reconstructed CT images, thus compromising its use in clinical diagnosis. A possible solution for reduction of beam hardening artefacts and furthermore minimizing patient dose is to use suitable x-ray spectra filtration by aluminium (Al) or copper (Cu) before penetration of the x-ray photons into the patient's body [2,3].

In this study, we have quantified the influence of using different x-ray spectra filtration on image quality, patient dose and modulation transfer function (MTF) in the GE LightSpeed VCT 64-slice cardiac CT scanner using experimental measurements.

II. MATERIAL AND METHODS

A. CT Scanner

The 64-slice LightSpeed VCT scanner (GE Healthcare Technologies, Waukesha, WI) equipped with Highlight ($Y_2Gd_2O_3$:Eu) ceramic scintillators was used in this study. This third generation CT scanner has 540 mm source to isocenter and 950 mm source to detector distance, 58,368 individual elements arranged in 64 rows of 0.625 mm thickness at isocenter, each containing 888 active elements and 24 reference elements. The scanner is equipped with the Performix Pro Anode Grounded Metal-Ceramic Tube Unit which uses 56 degree fan angle, 7 degree target angle and minimum inherent filtration of 3.25 mm Al and 0.1 mm Cu at 140 kVp.

B. Phantoms

A polyethylene cylindrical phantom (250±0.5 mm diameter) was constructed. This phantom consisted of 16 cylindrical holes (20±0.5 mm diameter) with four holes in the middle (5±0.5 mm diameter) which were filled with air. One of the 16 holes was filled with water and the rest with different concentrations of K_2HPO_4 in water (to model soft tissue and bones). The concentrations of K_2HPO_4 solution varied from 60 mg/cc to 1800 mg/cc to simulate bones with different densities (Fig. 1a). The phantom was scanned using four different tube voltages (80, 100, 120, 140 kVp), 200 mA tube current, 2 sec scan time, 5 cm slice thickness, and a small bowtie filter using different thicknesses of addition Al and Cu filter in the VCT 64-slice cardiac CT scanner. Radiation dose was measured using a pencil dosimeter placed in the central part of the phantom.

The GE performance phantom generally used for spatial resolution measurements and quality check was used for the assessment of the influence of filter thickness on overall image quality and MTF. The phantom consists of a cylindrical shell which is divided into three sections. The cylindrical shell is 21.6 cm Plexiglas with 20.3 cm in diameter. The first section of the phantom contains the patterns used to measure spatial resolution, slice thickness and laser light alignment. The second section contains low contrast resolution patterns whereas the third section contains water for measuring noise properties (Fig. 1c).

The head CT Dose Index (CTDI) Phantom was used for absorbed dose measurement when using different filter thicknesses. The head CTDI is made of solid acrylic, 15 cm thick, with diameters of 16 cm. It contains five probe holes, one in the center and four around the perimeter, 90° apart and 1 cm from the edge. The inside diameter of the holes is 1.31 cm. Each part includes five acrylic rods for plugging all the holes in the phantom (Fig. 1c).

C. Filters

Different thicknesses of Cu filters ranging from 0.13 to 1.6 mm, were mounted on the collimator aperture. All filters were cut in 4 cm ×10 cm dimension in order to be fit in the collimator box in the gantry of CT scanner. The filters fixed with special tape glue with very low x-ray attenuation coefficient.

D. Dosimetry

The DCT 10 RS pencil CT probe with Barracuda system was used for CT dosimetry. The DCT 10 RS is rugged, cylindrical pencil shaped air ionization chambers with flat energy response, and long term stability. The CT probes are intended for measuring and monitoring the exposure output level on CT scanners in a phantom or in air. CT dose index, CTDI, can be measured using this probe.
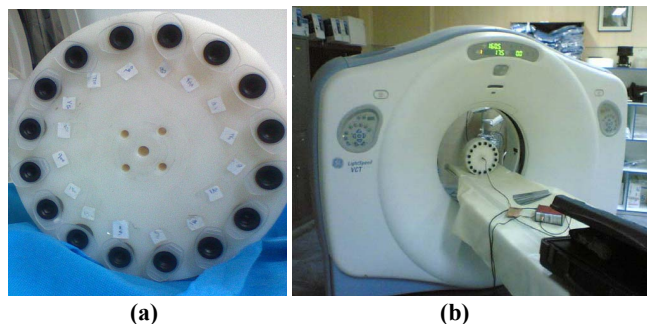
E. Assessment Strategy

The reconstructed images were analyzed through comparison of CT numbers (contrast) and standard deviation (noise) of different ROIs in the phantom with the values obtained using the default filtration of the scanner fixed in the factory. The contrast in each ROI was calculated using equation (1):

$$Contrast = \frac{d_x - d_{x'}}{d_x + d_{x'}} \qquad (1)$$

Where dx' is the mean CT number of the region with 0.12 mg/cc K_2HPO_4 chosen as reference material and dx is the CT number of various regions. Moreover the MTF using the GE performance phantom was calculated in order to quantify the influence of adding Cu filter on image quality and patient does. The measured dose in the center of CTDI phantom using pencil dosimeter was considered as a reference for patient dose when using different thicknesses of Cu filter. An objective figure of merit (FOM) was used to simultaneously evaluate the effect of filter thickness on contrast, dose and noise. It is calculated as the dose divided by the square of the signal to noise ratio. This FOM was calculated for various Cu thicknesses and the FOM curve normalized to one for zero filtration.

III. RESULTS

Fig. 1 shows the phantom and setup used for experimental measurements in this study. Fig. 2a shows the influence of using different cupper thickness fixed on the collimator of scanner on the CT numbers calculated for each region in polyethylene phantom at 140 kVp tube voltage, 200 mA tube current and 2 second rotation speed. Fig. 2b shows the calculated contrast using formula 1 for the CT numbers in Fig. 1a.
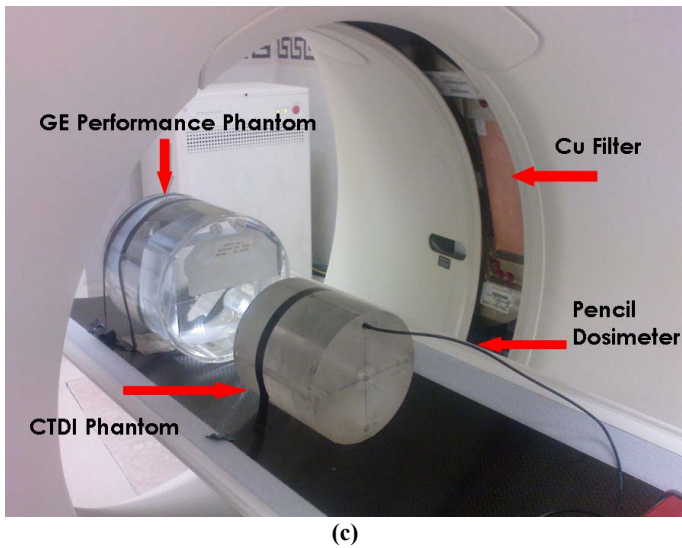

(a)   **(b)**

(c)

Fig. 1. Illustration of phantoms and experimental setup used in this study. (a) The Polyethylene phantom containing 16 cylindrical inserts. (b) The polyethylene phantom positioned within the scanner with the pencil dosimeter. (c) GE performance and CTDI phantoms, pencil dosimeter and copper filter attached to the collimator.
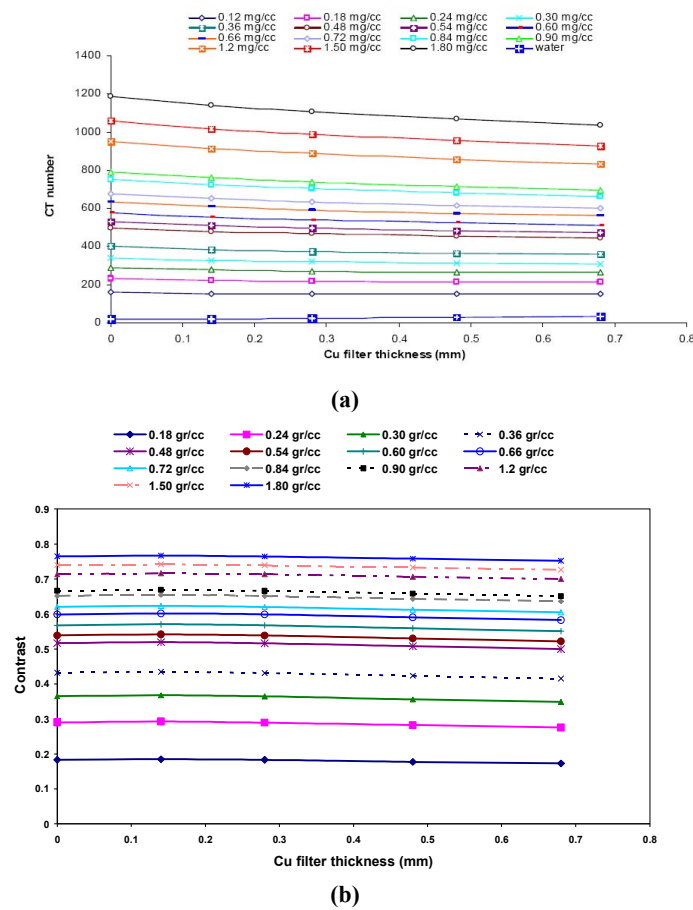

(a)

(b)

Fig. 2. Variation of CT number (a) and contrast (b) for different regions in the polyethylene phantom calculated using different Cu filter thicknesses used for filtration of the x-ray spectra at 140 kVp.

Fig. 3 shows a representative slice of the polyethylene phantom obtained using zero and 0.63 mm Cu filter thickness and the difference image. It should be emphasized that there is no significant difference between the two images.
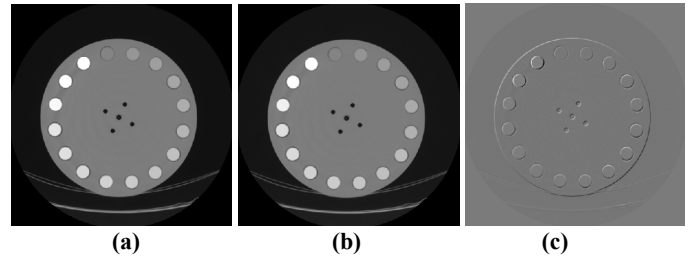

(a)   **(b)**   **(c)**

Fig. 3. Images acquired at 140 kVp, 200 mA and 2 sec rotation speed. (a) The image acquired without additional filter, (b) The image acquired in the same conditions as in (a) but with an additional 0.63 mm Cu filter, (c) The difference image between (a) and (b).

One of the main concerns in computed tomography imaging when using additional filters, for the purpose of dose reduction, is the increase of noise level in the image. Fig. 4 shows the calculated noise in the CT image of polyethylene phantom in different regions when using different thicknesses of cupper filter. There is slight increase of noise level with increasing filter thickness.
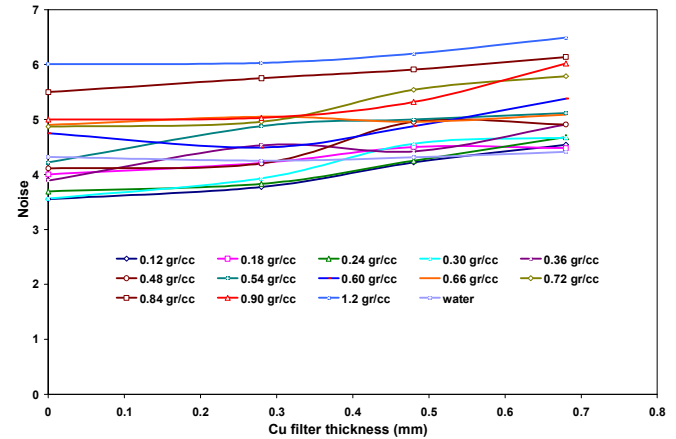

Fig. 4. Noise magnitude in different regions when using various thicknesses of Cu filter at 140 kVp and 200 mA.

Fig. 5 illustrates the influence of filter thickness on the measured dose in the center of the head CTDI phantom for various tube voltages. An exponential reduction of absorbed dose with increasing filter thickness is observed.

Fig. 6 shows the influence of using different Cu filter thicknesses on the resulting spatial resolution of images reconstructed using the GE performance phantom. The calculated MTF decreases with increasing filter thickness.

Fig. 5. Measured absorbed dose in the center of the head CTDI phantom when using different filter thicknesses for various tube voltages.

Fig. 6. (a) Representative slice of the GE performance phantom without filter, (b) The image of GE performance phantom with 1.61 mm u filter, (c) difference image, (d) MTF curves calculated for different Cu filter at 140 kVp.

Fig. 7 shows the FOM estimates as a function of Cu filter thickness for 120 and 140 kVp tube voltages. The curves are normalized to zero filtration and represent the variation of dose per unit detected photon for increasing Cu filtration. It should be emphasized that the initial rapid decrease in the FOM is associated with the reduction of unnecessary exposure by increasing Cu filter thus allowing to decrease patient dose without significant loss in image quality. The plateau region (slight variation of the FOM) indicates that increasing further the Cu thickness decreases the dose but also degrades image quality.

IV. DISCUSSION

The presented data in Fig. 2 shows slight decrease of CT number and contrast for different regions in the polyethylene phantom with increasing Cu filter thickness at 140 kVp tube voltage. The same behavior was observed for other tube voltages (data not shown). However visual qualitative and quantitative assessment of CT images acquired with various filter thicknesses shown in Figs. 3 and 4 seem to attest for a slight loss in image quality and increase of image noise. A significant decrease in dose with increasing filter thickness was shown in Fig. 5. Although Figs. 1-3 show that increasing filter thickness has slight influence on image contrast in the polyethylene phantom containing large objects, Fig. 6 seems to suggest a significant influence on contrast and spatial resolution in regions containing small objects. However according the definition of FOM measure, the filtration resulting in the minimum FOM is minimum, is the optimal one.
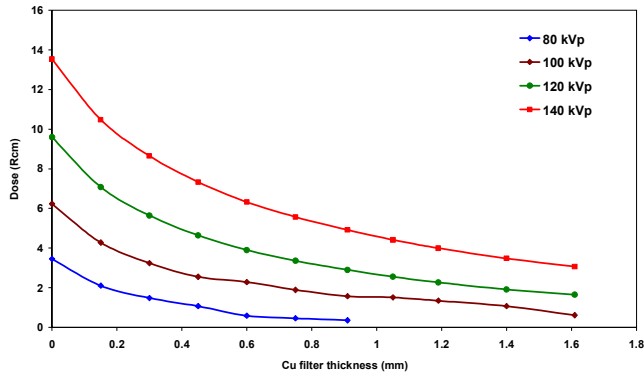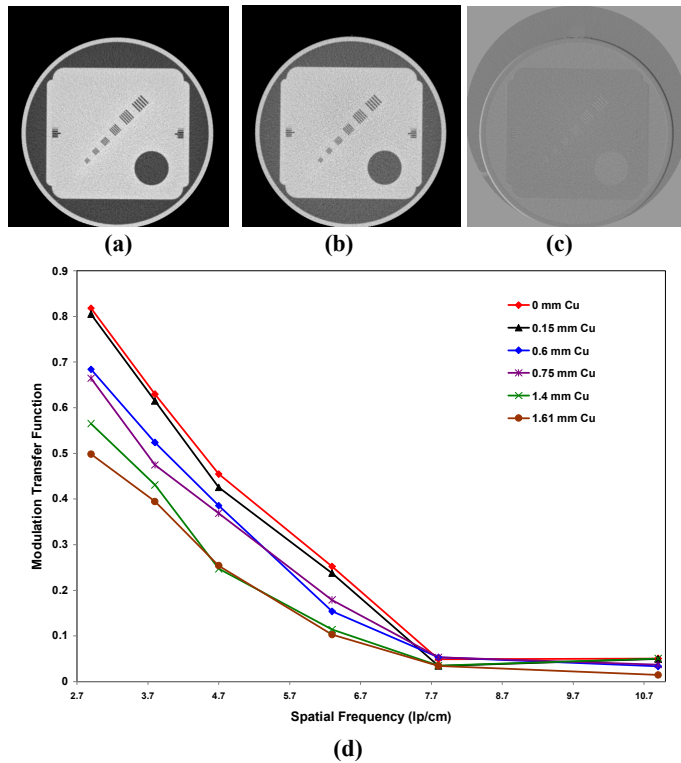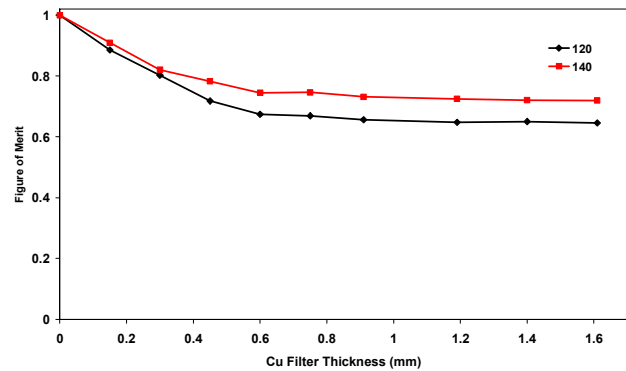

Fig. 7. Plot of figure of merit as a function of Cu filtration thickness (mm) in two different tube voltages.

V. CONCLUSION

The results suggest that increasing the x-ray spectra filtration dramatically decrease the patient dose while there is no considerable degradation of image quality with increasing filtration. In this study, we have presented preliminary results on the influence of filter material and thickness on image quality and patient dose. The additional filtration of 0.6 mm Cu was calculated as an optimal filter in order to present acceptable image quality with minimum dose. Nevertheless, this study is being refined by employing different filter thicknesses to accurately find the optimum filtration required for the GE VCT scanner to achieve the best image quality with the least possible patient absorbed dose.

REFERENCES

[1] [1] Morrell R., Rogers a.,Jobling J., Shakespeare K. "Barium enema: use of increased copper filtration to optimize dose and image quality" The British J. Rad., 77 (2004), 116–122

[2] [2] Robert J. Jennings, "A method for comparing beam-hardening filters materials for diagnostic radiology" Med. Phys. 15 (4), 1988, 588-599.

[3] [3] Massimiliano Szulc and Philip F. Judy, "Effect of x-ray source filtration on dose and image performance of CT scanners" Med. Phys. (6), 1979, 479-486.