ORIGINAL ARTICLE

Varying tube voltage and pitch effects on dose and image quality using single-energy CT

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Abstract:

Second generation of Computed Tomography (CT) with tin filtration is one of dose reduction strategies in advanced CT system. Taken advantage of high pitch mode as another parameter to reduce dose, will results in an increase spatial resolution and reduce acquisition time. In the present study, we have examined the effect of varying tube voltage and pitch on dose and image quality using Single-Energy CT with tin filter. a cow liver was used as an *ex vivo* phantom. The tube voltages were set at 80,100,120 and 140 kV whilst pitch factors 0.5, 0.6, 0.8, 1.0 and 1.2. Commonly, 120 kV and 1.0 pitch are used in standard protocol in CT, therefore, they are used as a reference for the study. The mean CTDIvol, Hounsfield Unit (HU) Number and Signal-to-Noise Ratio (SNR) at different level of kV and pitch were measured over a homogenous area of the liver phantom and the results were compared among the groups. In conclusion, performance of CT using 120 kVp and 1.2 pitch achieved reduction of radiation dose by 16% without impairing image quality with relatively higher SNR.

Keywords: CTDI volume; CT tube voltage; HU number; pitch; signal-to-noise ratio

1. INTRODUCTION

Due to the growing number of CT examinations, progress is being made to reduce radiation dose to patients [1]. Dose reduction strategies include reduction of tube voltage (kV), tube current (mAs), pitch, application of automated tube current modulation (ATCM), noise reduction filters, and image reconstruction techniques [2]. Reduction of kV allows overall dose reduction and improved image contrast [3]. It was found that performance of CT using a low tube voltage achieved reduction of radiation dose of 50% lower with the same image quality when compared with traditional abdominopelvic protocol [4]. The use of helical scanning allows pitch to be implemented in CT examinations. Pitch is a parameter used in helical CT that presented together with the introduction of the continuously moving table. It is described as the ratio of table feed in centimetres (cm) per 360° gantry rotation to the total nominal collimated x-ray beam width in the z direction. The dose can be decreased through the implementation of fixed mAs and by increasing the pitch [3]. Ibrahim, Parmar, Christodoulou & Mukherji [7] stated that the pitch value has a direct effect and is inversely proportional to the radiation dose of the patient. Beam collimation, table speed, and pitch are connected parameters that affect the diagnostic quality and radiation dose. Although there have been some reports about the technique, however there is limited study on abdominopelvic CT protocol. Therefore, the present study was performed to compare dose and image quality of CT liver protocol when the tube voltage and pitch varied, so that the liver parenchyma can be assessed.

2. MATERIALS AND METHODS

In this experimental study, a cow liver was used as an *ex vivo* phantom. It was weighted about 500 grams which was less than previous study [8]. In their study, about 6.5 kilogram of calf liver was used. Normal CT attenuation of the liver in non-contrast studies varies among people and ranging from 38 to 70 HU. In this study, the CT attenuation of the phantom was 63.6 HU and it was within the range of 38 to 70 HU. Next, the liver was cleaned dried to prevent bacteria growth before embedded in a gelatine mixture [9].

2.1 CT Acquisition

This study was performed using single-energy dual-source CT (DSCT) scanner 2x126 slices (Definition Flash AG, Siemens Healthcare). The protocol used for CT scanning was liver plain protocol (for adult body habitus). There were two technical parameters manipulated in this study which were tube voltage and pitch. The acquisition started with the lowest kV among the groups which were 80 kV, combined with pitch of 0.5 which was the lowest pitch (Table 1).

Table 1: Tube voltages and pitch used in the study

kV	Pitch
80	0.5
100	0.6
120	0.8
140	1.0
	1.2

Tin (Sn) filter was used throughout the experiment. The slice thicknesses of the images were set at 1.0 mm, whilst mAs were set at fixed value, 250 mAs. All images were reconstructed with filtered back projection (FBP) using reconstruction kernel of B26f (medium smooth).

2.2 Radiation Dose Estimation

The CTDI volume dose index of each CT acquisition was recorded [10, 11].

2.3 Noise Evaluation

The middle slice for each scan was chosen to be evaluated by adding circular ROIs in the image. To maintain constant circular region of interest (ROI) area, the ROIs were ranged from 0.8 to 2.0 cm^2 [11]. The size of each ROI was ±0.80 cm^2. The ROIs were named as ROI_1, ROI_2 and ROI_3 and they were distributed over homogenous area of the liver (Figure 1). To ensure consistency in the phantom, the ROIs were copied and pasted to subsequent acquisitions. The mean attenuation value (HU) and SD which representing the noise of each ROI were recorded [5].

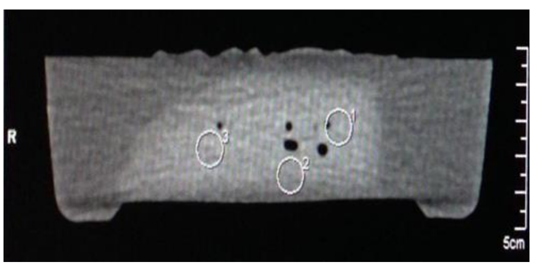

Figure 1: The three ROIs were placed over a homogeneous area of the liver.

2.3.1 SNR Value

For each specific ROI, the signal–to-noise ratio (SNR) was calculated by dividing the mean attenuation value with SD using the equation below [10],

$$\text{SNR} = \frac{Mean\ attenuation\ (HU)}{\text{SD (HU)}}$$

2.3.2 Subjective Image Evaluation

To compare the image quality from different tube voltage and pitch, CT image evaluation was done by two senior radiographers with at least 10 years of working experience in CT imaging. The images were presented with window width of 300 HU and window level of 40 HU. However, the evaluator was free to adjust the image display. The CT images were organised randomly, and the readers were blinded to the image acquisition parameters. All readings were performed on a Picture Archiving and Communications System (PACS) integrated workstation. The image scales for overall image quality were (1–inadequate for diagnosis;2–acceptable; 3–adequate; 4–optimal), noise (1–very noisy, unacceptable; 2–average noise; 3–less than average noise; 4–minimum or no noise), sharpness (1– very blurry, unacceptable; 2–acceptable;3–adequate; 4–very sharp), and artefacts (1– unacceptable; 2–mild artefacts; 3–negligible artefacts; 4–no artefact) [10].

2.4 Statistical Analysis

The normality test between independent groups; kV and pitch with dependent groups; CTDI vol., Mean HU / CT number, SD and SNR were analysed. Shapiro-Wilk test was used to analyse the data normality as the test was more accurate and specifically used for small sample sizes. One-Way ANOVA was conducted for quantitative data whilst for subjective image evaluation, the inter-evaluator agreement was assessed using Cohen's weighted kappa test. All analyses were performed using statistical software IBM SPSS Statistics 21.0.

3. RESULTS AND DISCUSSION

3.1 Radiation Dose

Table 2 shows how the mean CTDIvol varied with pitch value, with peak x-ray tube voltage ranging from 80 to 140 kVp. Most CT examinations are performed at 120 kVp and pitch 1.0 (standard value). The CTDIvol measured was 0.57 (indicated by *). The lowest CTDIvol in 120 kVp group was 0.48 at 1.2 pitch (indicated by **bold**). The percentage difference compared to standard kVp-pitch was 15.79%. Whilst, lower tube voltage with closest CTDIvol was at 100 kVp, 0.8 pitch (CTDIvol=0.49, p=0.508, indicated by **bold**). The percentage difference compared to standard kVp-pitch was 16.33%. The two values were highlighted to show the closest value to that of standard kVp-pitch.

Table 2: CTDI vol. using different combinations of kV and pitch

CTDI vol.								
kV/pitch	**80**	**%Diff.**	**100**	**%Diff.**	**120**	**%Diff.**	**140**	**%Diff.**
0.5	0.39	-31.58	0.78	36.84	1.15	101.75	1.77	210.53
0.6	0.33	-42.11	0.65	14.04	0.96	68.42	1.48	159.65
0.8	0.23	-59.65	**0.49**	**-16.33**	0.72	26.32	1.04	82.46
1.0	0.19	-66.67	0.39	-31.58	0.57*	0.00	0.88	54.39
1.2	0.14	-75.44	0.33	-42.11	**0.48**	**-15.79**	0.74	29.82

* Standard kVp-pitch (120 kVp, 1.0 pitch); **Bold** closest value compared to standard kVp-pitch

There was statistically significant difference of CTDI vol. using different kVp (p=0.001). The finding was in agreement with previous study where radiation dose change is proportional to the square of the voltage change [12].

3.2 Quantitative Image Analysis

Table 3 shows how the SNR values varied with tube voltage and pitch. At routine CT parameters (120 kVp and 1.0 pitch), computed SNR was 3.21. For the phantom homogenous area, increasing the x-ray tube voltage from 80 kVp to 140 kVp increased the photon energy, therefore, increased the SNR, which shows that the increase in radiation transmitted and received by the detector than the reference. With reference to 120 kVp and 1.2 pitch (CTDIvol. = 0.57), mean computed SNR (for CTDIvol. = 0.48) was increased (1.87%) than the reference (SNR=3.27, indicated by **bold**) (p>0.05). Unlike 100 kVp, 0.8 pitch

(CTDIvol. = 0.49), the SNR (2.84) was decreased by 11.53% (indicated by **bold**).

Table 3: SNR using different combinations of kV and pitch

	SNR							
kV/pitch	**80**	**%Diff.**	**100**	**%Diff.**	**120**	**%Diff.**	**140**	**%Diff.**
0.5	2.82	-12.15	3.26	1.56	3.82	19.00	4.51	40.50
0.6	2.36	-26.48	3.63	13.08	3.79	18.07	3.95	23.05
0.8	2.14	-33.33	**2.84**	**-11.53**	3.26	1.56	3.83	19.31
1.0	2.46	-23.36	2.85	-11.21	3.21*	0.00	3.67	14.33
1.2	1.82	-43.30	2.76	-14.02	**3.27**	**1.87**	3.97	23.68

* Standard kVp-pitch (120 kVp, 1.0 pitch); **Bold** closest value compared to standard kVp-pitch

Tang *et al.*, (2018) [17] stated that decreases of tube current and voltage will lead to increased image noise. It was supported by Khawaja et al. (2014) [6] that greater image noise and more image artefacts can worsen diagnostic quality, although reduction of radiation dose is evident. Total mean SNR values for 100-120 kVp [14] and 120-140 kVp showed no significant differences, p=0.314 and p = 0.113, respectively. However, total mean SNR for 140 kVp was significantly higher than total mean SNR for 100 kVp.

There was similar trend can be seen for mean attenuation number (CT Number) and Noise (SD) across the kVp groups. Also, no significant differences were found for these parameters for 100-120 kVp and 120-140 kVp. Variation of pitch does not affect CTDI vol. This is agreed by Ranallo & Szczykutowicz [13], when changes in pitch value would not affect radiation dose and image noise, particularly when AEC system is used. CT manufacturer has pre-set a specific dose and noise level according Dose Reference Levels guidelines. The AEC will increase the mAs to keep the dose and noise constant if the pitch was increased. Mayo-Smith, Hara, Mahesh, Sahani & Pavlicek [3] also stated that if pitch is increased with the use of effective mAs setting, the mAs will automatically increase to maintain image quality. Thus, the effect of changing pitch to radiation dose is not affected.

There was no statistically significant difference of SNR using different pitch. The finding was supported by Lança et al. [15]. They found that there was no significant difference of SNR values when three different pitch were assessed.

3.3 Qualitative Image Analysis

The overall image quality results from two observers were analysed using Cohen's weighted kappa test [16]. The degrees of inter-evaluator agreement for each image characteristics were determined by calculating the κ value.

We found that image of 120 kVp and 1.2 pitch (Figure 2) was in high agreement between the observers. These technical parameters produced lower CTDIvol (0.48) and higher SNR value (3.27) compared to the reference (120 kVp, 1.0 pitch; CTDIvol.=0.57, SNR=3.21). The findings were in agreement with Chen, Jin, He & Zhao (2014) [10]. These values produced better SNR, although no significant results were found.

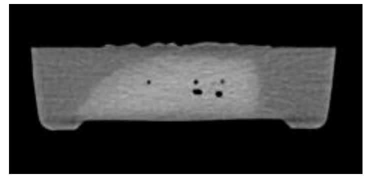

Figure 2: 120 kVp and 1.2 pitch image with minimum or no noise, an adequate sharpness and negligible artefacts.

4. CONCLUSION

In conclusion, performance of CT using 120 kVp and 1.2 pitch achieved reduction of radiation dose by 16% without impairing image quality with relatively higher SNR.

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REFERENCES

[1] Merzan, D., Nowik, P., Poludniowski, G., & Bujila, R., "Evaluating the impact of scan settings on automatic tube current modulation in CT using a novel phantom," *The British Journal of Radiology*, vol. 90, no. 1069, pp. 20160308., 2017.

[2] Gariani, J., Martin, S., Botsikas, D., Becker, C., & Montet, X., "Evaluating the effect of increased pitch, iterative reconstruction and dual source CT on dose reduction and image quality," *The British Journal of Radiology*, vol. 91, no. 1088, pp. 20170443, 2018.

[3] Mayo-Smith, W., Hara, A., Mahesh, M., Sahani, D., & Pavlicek, W., "How I do It: managing radiation dose in CT," *Radiology*, vol. *273, no.* 3, pp. 657-672, 2014.

[4] Huda, W., Scalzetti, E.M. & Levin, G., "Technique factors and image quality as functions of patient weight at abdominal CT", *Radiology*, vol. 217, no. 2, pp. 430-435, 2000.

[5] Papadakis, A., & Damilakis, J., "Automatic tube

current modulation and tube voltage selection in pediatric computed tomography," *Investigative Radiology*, vol. 54, no. 5, pp. 265-272, 2019.

[6] Khawaja, R., Singh, S., Otrakji, A., Padole, A., Lim, R., & Nimkin, K. et al., "Dose reduction in pediatric abdominal CT: use of iterative reconstruction techniques across different CT platforms," *Pediatric Radiology*, vol. 45, no. 7, pp. 1046-105, 2014.

[7] Ibrahim, M., Parmar, H., Christodoulou, E., & Mukherji, S., "Raise the bar and lower the dose: current and future strategies for radiation dose reduction in head and neck imaging," *American Journal of Neuroradiology*, vol. 35, no. 4, pp. 619-624, 2013.

[8] Agostini, A., Mahmood, U., Erdi, Y., Borgheresi, A., Ragucci, M., & Sawan, P. et al., "Quantification of iodine concentration using single-source dual- energy computed tomography in a calf liver," *Journal Of Computer Assisted Tomography*, vol. 42, no. 2, pp. 222-229, 2018.

[9] Lediju Bell, M., Kuo, N., Song, D., & Boctor, E., "Short-lag spatial coherence beamforming of photoacoustic images for enhanced visualization of prostate brachytherapy seeds," *Biomedical Optics Express*, vol. 4, no. 10, pp. 1964-1977, 2013.

[10] Chen, C., Lin, Y., Hsu, M., Hung, C., Liao, Y., & Tsai, H., "Performance of adaptive iterative dose reduction 3D integrated with automatic tube current modulation in radiation dose and image noise reduction compared with filtered-back projection for 80-kVp abdominal CT: Anthropomorphic phantom and patient study," *European Journal of Radiology, vol.* 85, no. 9, pp. 1666-1672, 2016.

[11] Quaia, E., "Comparison between 80 kV, 100 kV and 120 kV CT protocols in the assessment of the therapeutic outcome in HCC," *Liver and Pancreatic Sciences*, vol. *1, no.* 1, pp. 1- 4, 2016.

[12] Rezazadeh, S., Co, S., & Bicknell, S., "Reduced kilovoltage in computed tomography–guided intervention in a community hospital: effect on the radiation dose," *Canadian Association of Radiologists Journal*, vol. *65*, no. 4, pp. 345-351, 2014.

[13] N. Ranallo, F., & Szczykutowicz, T., "The correct selection of pitch for optimal CT Scanning: avoiding common misconception," *Journal of the American College of Radiology*, vol. *12*, no. 4, pp. 423-424, 2015.

[14] Rusandu, A., Ødegård, A., Engh, G., & Olerud, H., "The use of 80 kV versus 100 kV in pulmonary CT angiography: An evaluation of the impact on radiation dose and image quality on two CT scanners," *Radiography*, vol. 25, no. 1, pp. 58-64, 2019.

[15] Lança et al., "The impact of pitch values on image quality and radiation dose in an abdominal adult phantom using CT," *Researchgate*. doi: DOI: 10.1594/ecr2017/C-2755, 2017.

[16] Tang, W., Hu, J., Zhang, H., Wu, P., & He, H., "Kappa coefficient: a popular measure of rater agreement," *Shanghai Archives of Psychiatry*, vol. 27, no. 1, pp. 62-67, 2015.

[17] Tang, Y., Liu, Y., Hsu, M., Tsai, H., & Chen, C., "Adaptive iterative dose reduction 3D integrated with automatic tube current modulation for CT coronary artery calcium quantification: comparison to traditional filtered back projection in an anthropomorphic phantom and patients", *Academic Radiology*, vol. 25, no. 8, pp. 1010-1017, 2018.