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The investigation of dose and image quality of chest computed tomography using different combinations of noise index and adaptive statistic iterative reconstruction level

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Abstract

Background: Computed tomography (CT) automatic tube current modulation (ATCM) systems and iterative reconstruction (IR) play an important role in CT radiation dose optimization. How the two can best be used together is one of the challenges faced by radiology professionals. **Aim:** To determine optimum settings of ATCM noise index (NI) together with adaptive statistic iterative reconstruction (ASIR) for a general electric (GE) scanner that aims to achieve similar image quality to the standard protocol used in the hospital (Smart mA technique with NI of 11.57 and 30% ASIR reconstruction) with a lower dose. **Methods:** Different NI and ASIR levels were set for scans of a phantom. Objective image quality assessments in terms of noise, signal-to-noise ratio (SNR), contrast-to-noise ratio (CNR), low-contrast detectability (LCD), and modulation transfer function (MTF) were carried out in an anthropomorphic chest and a Catphan 700 phantom. Subjective image quality assessment was also performed with five readers to confirm whether the image quality of the new protocols was adequate. **Result and Conclusion:** SNR and CNR increased with the strength of ASIR, and decreased with higher NI settings. The MTF improved slightly for higher dose levels and from filtered back projection (FBP) to higher strength of ASIR. LCD improved with ASIR compared to FBP and with higher strengths of ASIR. Qualitative scoring ranged between 3.0 and 4.6. A moderate degree of reliability was found between scoring. Use of NI 15.04 with 70% ASIR can reduce dose by 41% compared to the standard protocol of NI 11.57 with 30% ASIR without degradation of image quality.

Key words: Adaptive statistic iterative reconstruction; automatic tube current modulation; computed tomography optimization

Introduction

Computed tomography (CT) examinations are now common medical procedures, as the scans facilitate rapid and more accurate diagnosis. Radiation-induced carcinogenesis is a stochastic effect, whose probability increases with radiation dose. Several models of radiation-induced cancer have been

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reported in the literature.[1] However, the dramatic rise in the use of CT has been responsible for the increased medical exposure to ionizing radiation,[2] so there is a need to ensure that radiation protection methods for CT procedures are optimized in order to keep dose levels to a minimum.

CT scans of the chest are one of the more common examinations used in the diagnosis of chest disorders, such as infection, inflammation, and cancer, and are also being considered in screening for lung cancer. A recommendation has been made that this application of CT should be justified for dose levels with the volume-weighted CT dose index ($CTDI_{vol}$) <3.0 mGy for standard size patients.[3,4] Effective dose is the parameter related to the risk from exposure to ionizing radiation. For CT, it can be calculated from multiplication of the dose length product (DLP) by a DLP to effective dose conversion factor. DLP is based on the product of $CTDI_{vol}$ and irradiation length for the scan. There have been some studies that demonstrate the possibility of reducing radiation exposure using low-dose CT protocols, to give effective dose in the dose range of chest radiography.[5] These doses are now in the realm that could enable justification for using low-dose CT instead chest radiography for some applications. A survey in Thailand has reported that the average values of $CTDI_{vol}$ and effective dose for chest CT are about 10 mGy and 5 mSv, respectively.[6] For CT scans to be used for such purposes, a level of image quality must be maintained to ensure that the scans provide the required diagnostic information.

To optimize radiation dose in CT, various technological strategies can be applied. Modern CT scanners incorporate automatic tube current modulation (ATCM) systems to reduce patient doses. These are designed to aid in maintaining optimized radiation dose and consistent image quality throughout CT scans and for patients of varying size.[7-10] In principle, the tube current is adjusted automatically to that appropriate for the X-ray attenuation of the patient cross-section being scanned. Current scanners also incorporate iterative reconstruction (IR), a CT reconstruction algorithm that is able to give a lower image noise level when compared to the filtered back projection (FBP) reconstruction method.[11-13]

Use of a combination of ATCM and IR has the potential to further reduce the dose while maintaining image quality. In the present study, a general electric (GE) system with a Smart mA ATCM and adaptive statistic iterative reconstruction (ASIR) was used. The goals of this study were to investigate the use of IR together with the ATCM to determine how the two can best be applied together, and to establish a new protocol implementing Smart mA and ASIR that can be used as a CT low-dose protocol providing an acceptable level of image quality similar to that for the routine protocol used in the hospital.

Methods

Ethical approval (No. 0348/60) was obtained from the Institutional Ethics Committee. Because the qualitative image quality assessment was performed by radiological technologists, informed consent was obtained from human participants. Experiments were carried out on an anthropomorphic phantom and a Catphan image quality phantom. An Alderson chest phantom (RSD model RS330) was used for this study. It extends from the neck to below the diaphragm, and is molded around a male skeleton, corresponding to a patient that is 175 cm tall and 73.5 kg in weight. The materials are equivalent to natural bone and soft tissues. Lungs are fixed in the inflated state and are molded to conform to the pleural cavities of the phantom. The pulmonary arteries are injected with a blood equivalent plastic.

Measurements were performed using a 128-slice CT scanner from GE Healthcare (Optima 660). In the present study, Smart mA which is x–y plane and z-axis modulation was used.[14] The standard protocol used by the hospital is a NI of 11.57 HU, 120 kVp, 0.8 s rotation time, 1.375 pitch factor, 40 mm beam collimation, 5 mm slice thickness, and standard filter. Image data set was reconstructed using 30% ASIR. The scanned region covered the entire lung fields. The range of the tube current was between 10 and 350 mA. Scans were performed with the reference default NI of 11.57 and other NI settings of 13.3, 15.04, 16.78, 18.52, 20.26, and 22 (NI was increased by 15 for each setting). Each image data set was reconstructed using three different ASIR levels of 30, 50, and 70%. Details of the standard chest protocol used by the hospital and the other protocols developed are summarized in Table 1.

For every scan, $CTDI_{vol}$ in mGy and DLP in mGy cm were recorded. Values for effective dose were then calculated as effective dose = DLP × E_{DLP}, where E_{DLP} is a DLP to effective dose conversion factor with a value for the chest of 0.015 mSv/mGy cm.[15,16] The quantitative analysis of the images in terms of pixel value (signal) and standard deviation of the pixel value (noise) were carried out using Image J.[17] The pixel value and standard deviation of the pixel value from images recorded near the middle level of the scan for slice numbers 23-25, 28-33, and 36 were measured. Ten regions of interest (ROIs) each 5 mm in diameter were placed within the lung and soft tissue for each slice (three reconstructions for each acquisition protocol), as shown in Figure 1. Brightness was adjusted for viewing by the radiological technologist, who was asked to position the ROI for one image series, and the coordinates of individual ROIs were recorded and the same positions used for all image series.

The image quality was then evaluated by calculating the signal-to-noise ratios (SNRs) in the lungs and soft tissue,

Table 1: CT protocols and dose data

Protocol	Dose step	NI	ASIR level (%)	$CTDI_{vol}$ (mGy)	DLP (mGy cm)	Effective dose (mSv)
Standard	0	11.57	30	5.2	211	3.0
1			50			
2			70			
3	−3	13.3	30	3.9	160	2.2
4			50			
5			70			
6	−6	15.04	30	3.1	125	1.8
7			50			
8			70			
9	−9	16.78	30	2.5	100	1.4
10			50			
11			70			
12	−12	18.52	30	2.0	82	1.2
13			50			
14			70			
15	−15	20.26	30	1.7	69	1.0
16			50			
17			70			
18	−18	22	30	1.4	59	0.8
19			50			
20			70			

NI=Noise index, ASIR=Adaptive statistic iterative reconstruction, $CTDI_{vol}$=Volume weighted computed tomography dose index, DLP=Dose length product

and contrast-to-noise ratios (CNR) for the lung and soft tissue as follows:

$$SNR = \left| \frac{HU_{ROI}}{\sigma_{ROI}} \right| \quad (1)$$

$$CNR = \frac{\left| HU_{Lung} - HU_{Soft\ tissue} \right|}{\sqrt{\frac{\sigma^2_{Lung} + \sigma^2_{Soft\ tissue}}{2}}} \quad (2)$$

where σ corresponds to the standard deviation of pixel value in the ROIs.

The Statistical Package for the Social Sciences (SPSS) statistical package version 23 (SPSS Inc., Chicago, IL, USA) was used for statistical analysis. Analysis of variance (ANOVA) was used to assess the differences in SNR and CNR between the group means, at α=0.05. If significant differences were found, *post-hoc* analysis would be used by dependent *t*-test to test the difference between protocols at α = 0.01 (Bonferroni adjustment for five comparisons). Protocols having similar (not statistically different) or higher values of SNR and CNR compared to the standard protocol were considered and were then further evaluated by subjective image quality assessment.

For qualitative image quality analysis, images were evaluated by five observers each with more than 7 years' experience of interpreting CT images, and blinded to the CT settings. Image quality was assessed using the following criteria: image noise, contrast, sharpness and image artifact. Images for 5 mm slice thicknesses were assessed with fixed windowing of lung images at a window width of 1500 HU and window level of −600 HU, and mediastinum images at a window width of 350 HU and window level of 50 HU. The evaluation form was based on a five-level Likert scale (1–5); higher scores indicating better image quality. Intra-class correlation (ICC) was calculated for evaluation of the correlation between observers and the nonparametric Friedman test with significance level at $P < 0.01$ was used to evaluate whether the subjective image quality for the newly developed protocols differed from that for the standard protocol.

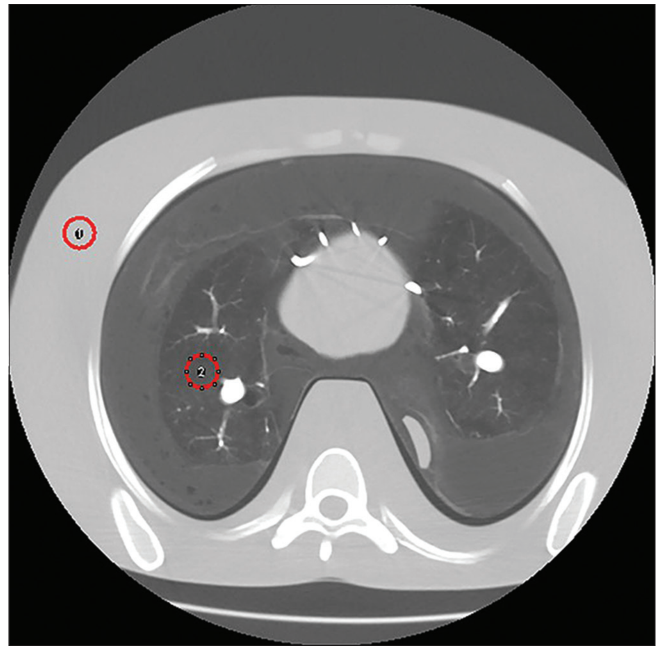

Figure 1: CT images of the chest phantom at the middle of the heart obtained from standard protocol and ROI locations

Image quality assessment was carried out using images acquired from a Catphan 700 phantom (The Phantom Laboratory, Inc., Salem, NY).[18] The scan parameters were 120 kV, field of view 240 mm, and slice thickness of 5 mm. Other scan settings were similar to those used for the anthropomorphic phantom. As the Catphan is cylindrical in shape, it does not reflect mA modulation. Therefore, the mA was selected to achieve values for the $CTDI_{vol}$ of 1.4, 1.7, 2.0, 2.5, 3.1, 3.9 and 5.2 mGy, according to the $CTDI_{vol}$ result from the chest phantom. Measurements of CT number from various materials such as air, lung foam, polystyrene, 20 and 50% hydroxyapatite (CTP682), as well as low-contrast detectability (LCD) (CTP 515), and spatial resolution at 50 and 10% levels of the modulation transfer function (MTF) from 50 μm Teflon wire (CTP682) were performed. The CNR was calculated using the contrast between the values of signal measured at 1% contrast of 15 mm in diameter at

CTP515 and the signal measured at the background next to the contrast object, and divided by the noise which was the mean of the standard deviation of the three ROIs located on the background,[19] as shown in Equation (3).

$$\text{CNR}=\left|\frac{\text{Object}_{\text{HU}}-\text{Background}_{\text{HU}}}{\text{Backgound standard deviation}}\right| \quad (3)$$

Images were reconstructed using the standard kernel for FBP and 30, 50 and 70 ASIR. Web-based software provided by Image owl® was used for the analysis.[20]

Results

Dose and quantitative image quality assessment from anthropomorphic phantom

Changing the NI settings from 11.57 through to 22 resulted in reductions in DLP from 25 to 72% [Table 1], corresponding to the tube current reductions shown in Figure 2. Results for the SNR measured in the lung and soft tissue and CNR between the lung and soft tissue are shown in Table 2. $\text{SNR}_{\text{soft tissue}}$, SNR_{lung}, and CNR for the standard protocol were 3.3, 90.7, and 137.1, respectively. Figure 3 and Table 2 show the SNR and CNR values for each protocol for individual NI settings. The SNR and CNR increased with the strength of ASIR, and decreased with higher NI settings [Figure 3 and Table 2]. Statistical analysis showed that values for the SNR and CNR for protocol numbers 1, 2, 4, 5, and 8 were similar to or higher than those of the standard protocol.

Qualitative image assessment

Qualitative scoring of image noise, contrast, sharpness, and image artifact from the five readers are shown in Table 3, scores ranged between 3.0 and 4.6. A moderate degree of reliability was found between scoring. The average measure of ICC was 0.52 with a 95% confidence interval from 0.205 to 0.744 ($P < 0.001$). For the acceptability of the image noise level, all developed protocols received similar or higher scores compared to the standard protocol, while those for the contrast and sharpness received lower scores

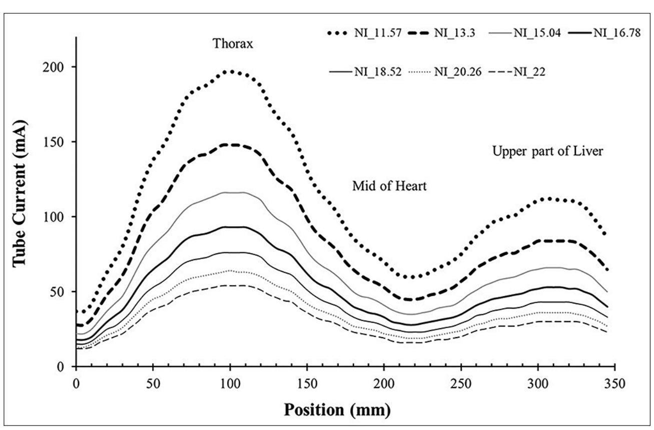

Figure 2: Tube current (mA) modulations for individual protocols

(from scores of 4–5 for each reader, to scores of 2–4). However, the difference in the mean image quality score in each category of image noise, contrast, sharpness, and image artifact was not statistically significant.

Image quality assessment from Catphan

Values for CT number measured from air, lung foam, polystyrene, 20 and 50% hydroxyapatite using the standard protocol were 947, −776, −33, 236, and 663 HU, respectively. CT numbers varied slightly but were within ±2 HU for each material and reconstruction method. CNR and noise analysis with the Catphan showed improvements when using ASIR compared to the FBP [Figure 4A and B]. CNR was 16–30, 30–57, and 47–89% higher, for higher dose settings, for 30, 50, and 70% ASIR, respectively, and the noise was reduced by up to 5 HU when using 70% ASIR.

Results for high-contrast spatial resolution are illustrated by the MTF curves for the different reconstruction methods. At a CTDI_{vol} of 1.4 mGy, values for the 50% level were 3.8, 3.9, 4.0, and 4.1 lp cm^{-1}, while the number of lp cm^{-1} increased to 6.7, 6.8, 6.9, and 7.0 at 10% MTF for FBP and 30, 50, and 70% ASIR, respectively. The MTF improves slightly for higher dose levels and showed a steady progression from

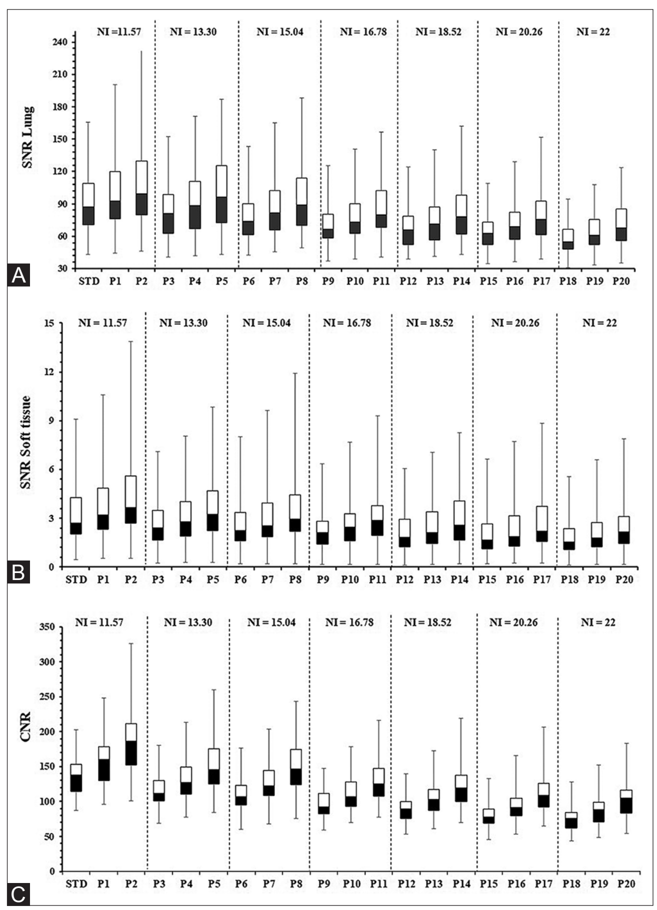

Figure 3 (A-C): SNR measured at the lungs (A) and soft tissue (B) and CNR (C) for individual protocols

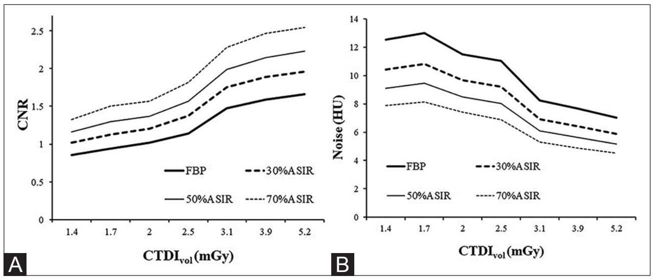

Figure 4 (A and B): CNR (A) and noise (B) for different reconstruction methods and dose levels

FBP to higher strength of ASIR. Figure 5 shows MTF for the recommended protocol of 3.1 mGy.

Results for the LCD are shown in Figure 6. Lower dose settings with the same reconstruction methods and contrast level tended to give lower abilities to identify objects. With the same dose and contrast level, smaller detail diameters could be detected with ASIR compared to FBP and with higher strengths of ASIR.

Discussion

As ATCM systems and IR have been widely used, the effectiveness of dose reduction has been studied. Several investigators have published data relating to the efficiency of ASIR for pathologic findings, such as reticulations, nodules, and bronchiectasis, in reducing dose by 32–65%for patient examinations, without increasing the noise level in the reconstructed images.[12,20-23] The efficiency of ASIR when used together with ATCM has been studied by Qi *et al.* who suggested that use of 50% ASIR with a NI setting of 15 allowed a dose reduction of 57% for chest CT.[24]

Image quality improved when either higher dose or ASIR levels were set [Table 2 and Figure 3]. Results obtained from the Catphan phantom confirmed those from the chest phantom. The measured noise (standard deviation of the pixel value) from Catphan for the NI setting of 11.57 ($CTDI_{vol}$ of 5.2 mGy) reconstructed with FBP was about 7 HU. This was slightly lower than the targeted noise level. NI is defined as the standard deviation of pixel values in the central region of an image of a uniform water phantom. As the location of measuring noise was at the edge of the phantom, there was less attenuation of photons, therefore lower noise compared to the center. The results indicated that a higher level ASIR gave similar image quality compared to the lower level ASIR with a NI setting that was one step lower. For the standard protocol, the NI setting of 11.57 with 30% ASIR gave the measured noise of about 6 HU or 15% lower compared to the target value. From Figure 4B, similar noise value to the NI setting of 11.57 with FBP would be obtained for the NI setting of 15.04 with 30% ASIR, NI setting of 16.78 with 50% ASIR, and NI setting of 18.52 with 70% ASIR. Results for CNR varied in a similar way. This

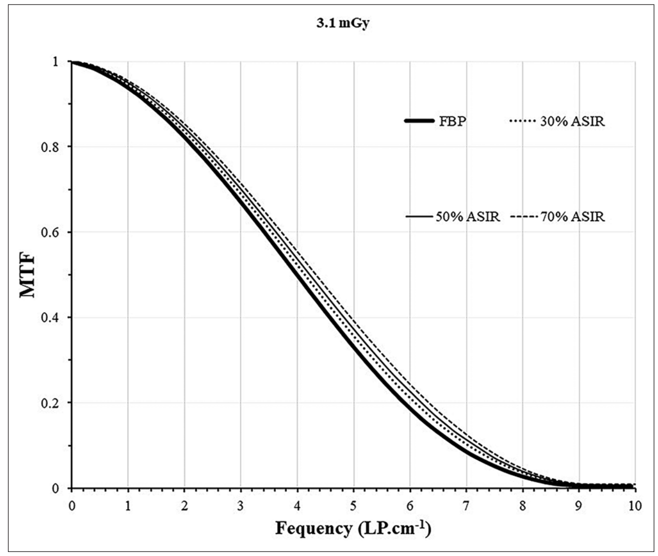

Figure 5: Variation of spatial resolution with different reconstruction methods for the recommendation protocol of 3.1 mGy

Table 2: Quantitative image analysis for different CT protocols

Protocol	NI	ASIR level (%)	SNR soft tissue	SNR lung	CNR
Standard	11.57	30	3.3	90.7	137.1
1		50	3.8	99.1	158.1
2		70	4.4	108.5	185.1
3	13.3	30	2.8	82.7	114.3
4		50	3.2	92.7	130.9
5		70	3.6	99.5	151.6
6	15.04	30	2.6	77.0	108.8
7		50	3.0	84.9	126.2
8		70	3.5	93.7	148.3
9	16.78	30	2.3	70.3	96.5
10		50	2.7	77.4	111.4
11		70	3.1	85.4	130.4
12	18.52	30	2.1	67.2	88.9
13		50	2.5	74.6	103.3
14		70	2.9	83.3	122.2
15	20.26	30	2.0	63.7	80.1
16		50	2.3	70.5	93.4
17		70	2.7	78.2	110.7
18	22	30	1.8	58.1	75.6
19		50	2.1	64.5	87.9
20		70	2.5	71.9	103.9

ASIR=Adaptive statistic iterative reconstruction, SNR=Signal-to-noise ratio, CNR=Contrast-to-noise ratio

indicated that, with the same noise level, users can set higher NI values when ASIR was implemented. The effect of ASIR on CT numbers for different materials was evaluated. All reconstruction methods gave relatively constant values of CT numbers with variations of up to 2 HU These results were similar to those reported by Dodge *et al.*[19]

Results of LCD showed improvement when using higher level of ASIR, especially for lower NI settings or higher dose. At 0.5 and 1% contrast, similar values of LCD were

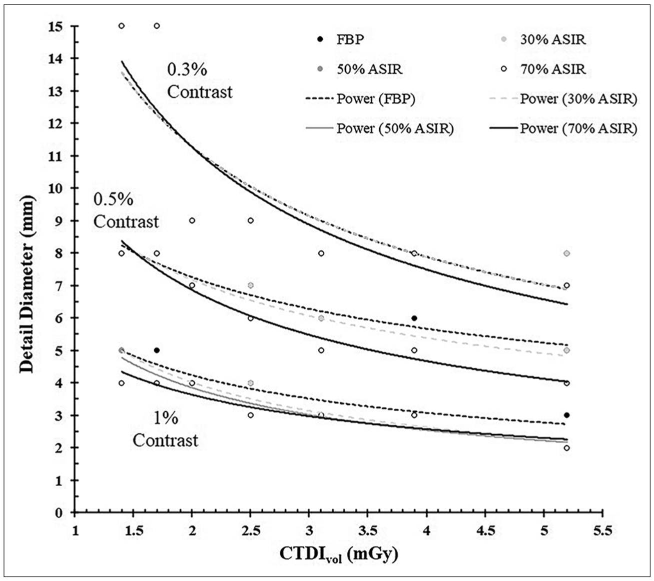

Figure 6: Variation of low-contrast detail detectability with dose levels and different reconstruction methods, for contrast levels of 1, 0.5, and 0.3%

Table 3: Overall scores of subjective image quality analysis

Protocol	Average qualitative image quality score (n=5)			
	Image noise	Sharpness	Contrast	Image artifact
Standard	3.20±0.84	4.20±0.84	4.60±0.55	3.60±0.55
1	3.40±0.55	3.80±0.45	4.00±0.00	3.20±0.45
2	3.60±0.55	3.00±0.71	3.20±0.84	3.20±0.45
4	3.80±0.84	3.60±0.55	3.60±0.55	4.40±0.55
5	3.20±0.45	3.20±0.84	3.80±0.45	4.00±0.71
8	3.40±0.55	3.80±0.45	3.80±0.45	3.40±0.55

P>0.01

found from use of the higher NI setting of 15.04 with 70% ASIR compared to the lower NI setting of 11.57 mGy with FBP [Figure 6]. For the 0.3% contrast object, there were no significant differences between ASIR and FBP for the NI settings higher than 16.78. This may be because the higher noise obscured the small differences between the target and background. Results imply that different NI and ASIR settings should be implemented for different investigations. Diffuse lung disease that is considered to be a low-contrast resolution task may not be detected with NI settings higher than 16.78.

The ability of CT image to detect small lung nodules is crucial for lung cancer screening. Sharpness in terms of MTF is capable of separating smaller objects from surroundings. Results showed the values were relatively constant for various NI (or dose) settings [Figure 5]. Comparisons of MTF between FBP and ASIR showed that higher level of ASIR improved resolution slightly. Results also suggested that the use of ATCM together with a higher level of ASIR has the potential for lung cancer screening because the results for noise, CNR, LCD, and MTF improved. SNR and CNR measured from P8 were similar to or better than those from the standard, P1, and P4 protocols but lower than those from P2 and P5 protocols [Table 2 and Figure 3]. However, image quality analysis based on noise and CNR measurements does not completely encompass the differences in image texture which may affect patient diagnoses. For the protocol P8, although the objective image quality was not significantly changed compared to the standard one, the subjective image quality scores in terms of contrast decreased from 4.6 to 3.8 [Table 3]. This may be because of a different appearance of the images from more statistical reconstruction of the CT data sets, noise and texture are different from those in the standard protocol, and this may give an unsatisfactory diagnostic result. Therefore, care must be taken not to use too high degree of ASIR as this could result in an over-smoothing artifact.[25,26] In detail, all readers gave scores of 4–5 for the contrast obtained from the standard protocol and 3–4 for that from the other protocols. However, there was one reader who gave a score of 2 for contrast and sharpness of protocol P2. This mismatching classification induced lower ICC among readers. In order to clarify whether the lower scores obtained had implication for diagnosis, the readers have been asked and confirmed that protocol P8 produced adequate image quality that is suitable for interpreting diagnostic images.

The optimal combination of setting a higher NI together with a higher percent of IR in order to achieve a lower dose while preserving acceptable image quality could be a way of following the ALARA principle. The objective of this study was to develop new protocols that have a similar level of image quality compared to the routine chest CT protocol of the hospital (Smart mA technique with the noise index of 11.57 and 30% ASIR reconstruction). The result suggested that protocol P8 provides the best CNR and SNR with the lowest effective dose. Doses obtained from the present study were lower than those reported from a survey in Thailand.[6] This is because the majority of CT scanners do not use IR and ATCM. $CTDI_{vol}$ can be reduced from 5.2 to 3.1 mGy (and effective dose from 2.96 to 1.75 mSv) [Table 1], which was about a 40% reduction while preserving a similar level of image quality with a NI of 15.04 and 70% ASIR. The image quality for both objective and subjective assessments were not significantly different from the routine protocol used in the hospital.

This study has several limitations. First, this was a phantom study and the results cannot be automatically transferred to humans. A slice thickness of 5 mm may not be adequate for major indications for chest CT such as interstitial lung disease, lung nodule, and pulmonary embolus. It is possible that this increased slice thickness enhanced measures such as SNR that could have otherwise produced more noise at thinner slices and also influenced the ideal NI and ASIR combination.[27-29] Lung CT images can be reconstructed using different filter reconstructions based on clinical indications and these will affect the image noise and MTF. Hhowever, the effect of such reconstructions on the image quality using the different variables has not been included in this study. Additional studies may be performed in order to determine the most efficient use of ATCM and ASIR with filter reconstructions. Second, CT dose optimization in this study was based on SNR and CNR only. Other advanced image quality parameters that take noise texture into account, such as the noise power spectrum, should be considered. Lastly, effective dose was calculated by using a generic DLP to effective dose conversion factor established for a broad range of different scanners and scan settings, and therefore can only be used to give a broad idea of the effective dose.

In summary, this phantom study evaluated quantitative and qualitative image quality of chest CT at different combinations of noise index and ASIR level. The new protocol of NI 15.04 with 70% ASIR can reduced the dose by 41% compared to the standard protocol of NI 11.57 with 30% ASIR without degradation of image quality. Because scan parameters affect CT ATCM system operation, additional studies should be performed in order to determine the most efficient use of ATCM and ASIR.

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Conflicts of interest

There are no conflicts of interest.

References

1. Candela-Juan C, Montoro A, Ruiz-Martinez E, Villaescusa JI, Marti-Bonmati L. Current knowledge on tumour induction by computed tomography should be carefully used. Eur Radiol 2014;24:649-56.
2. Amis ES, Butler PF, Applegate KE, Birnbaum SB, Brateman LF, Hevezi JM, *et al.* American College of Radiology white paper on radiation dose in medicine. J Am Coll Radiol 2007;4:272-84.
3. Kalra MK. Low-dose CT for lung cancer screening. J Am Coll Radiol 2017;14:719-20.
4. Fintelmann FJ, Bernheim A, Digumarthy SR, Lennes IT, Kalra MK, Gilman MD, *et al.* The 10 pillars of lung cancer screening: Rationale and logistics of a lung cancer screening program. Radiographic 2015;35:1893-908.
5. Ernst CW, Basten IA, Ilsen B, Buls N, Van Gompel G, De Wachter E, *et al.* Pulmonary disease in cystic fibrosis: Assessment with chest CT at chest radiography dose levels. Radiology 2014;273:597-605.
6. Trinavarat P, Kritsaneepaiboon S, Rongviriyapanich C, Visrutaratna P, Srinakarin J. Radiation dose from CT scanning: Can it be reduced? Asian Biomed 2011;5:13-21.
7. McCollough CH, Bruesewitz MR, James M. Kofler J. CT Dose reduction and dose management tools: Overview of available options. Radiographic 2006;26:503-12.
8. Kalender W. Computed Tomography: Fundamentals, System Technology, Image Quality, Applications. 2nd ed. Erlangen: Publicis Corporate Publishing; 2005.
9. Mulkens TH, Bellinck P, Baeyaert M, Ghysen D, Van Dijck X, Mussen E, *et al.* Use of an automatic exposure control mechanism for dose optimization in multi-detector row CT examinations: Clinical evaluation. Radiology 2005;237:213-23.
10. Kalra MK, Rizzo S, Maher MM, Halpern EF, Toth TL, Shepard JA, *et al*. Chest CT performed with z-axis modulation: Scanning protocol and radiation dose. Radiology 2005;237:303-8.
11. Geyer LL, Schoepf UJ, Meinel FG, Nance JW, Bastarrika G, Leipsic JA, *et al.* State of the art: Iterative CT reconstruction techniques. Radiology 2015;276:339-57.
12. Singh S, Kalra MK, Gilman MD, Hsieh J, Pien HH, Digumarthy SR, *et al.* Adaptive statistical iterative reconstruction technique for radiation dose reduction in chest CT: A pilot study. Radiology 2011;259:565-73.
13. Hsieh J. Adaptive statistical iterative reconstruction: GE white paper. Waukesha: Wis: GE Healthcare; 2008.
14. Bruesewitz MR, Yu L, Vrieze TJ, Kofler JM, McCollough CH. Smart mA: Automatic Exposure Control (AEC)—Physics Principles and Practical Hints. Cited 10 November 2016. Available from: http://www.mayo.edu/research/documents/smart-ma-automatic-exposure-control/doc-20086817?_ga=1.128355468.1026815034.1456709320.
15. Task Group on Control of Radiation Dose in Computed Tomography. Managing patient dose in computed tomography. A report of the International Commission on Radiological Protection. Annals of the ICRP 2000;30:7-45.
16. Shrimpton PC, Hillier MC, Lewis MA, Dunn M. National survey of doses from CT in the UK: 2003. Br J Radiol 2006;79:968-80.
17. Ferreira T, Rasband W. The Image J User Guide-Version 1.44. Cited 10 November 2016. Available from: http://imagej.nih.gov/ij/docs/user-guide.pdf.
18. The Phantom Laboratory 2017 Catphan® 700 User Manual. Salem, NY: The Phantom Laboratory.
19. Dodge CT, Tamm EP, Cody DD, Liu X, Jensen CT, Wei W, *et al.* Performance evaluation of iterative reconstruction algorithms for achieving CT radiation dose reduction-a phantom study. J Appl Clin Med Phys 2016;17:511-31.
20. ImageOwl. Image Owl Catphan® QA. Cited 25 December 2016. Available from: http://catphanqa.imageowl.com.
21. Leipsic J, Nguyen G, Brown J, Sin D, Mayo JR. A prospective evaluation of dose reduction and image quality in chest CT using adaptive statistical iterative reconstruction. AJR Am J Roentgenol 2010;195:1095-9.
22. Vardhanabhuti V, Loader RJ, Mitchell GR, Riordan RD, Roobottom CA. Image quality assessment of standard- and low-dose chest CT using filtered back projection, adaptive statistical iterative reconstruction, and novel model-based iterative reconstruction algorithms. AJR Am J Roentgenol 2013;200:545-52.
23. Ichikawa Y, Kitagawa K, Nagasawa N, Murashima S, Sakuma H. CT of the chest with model-based, fully iterative reconstruction: Comparison with adaptive statistical iterative reconstruction. BMC Med Imaging 2013;13:27.
24. Qi L-P, Li Y, Tang L, Li Y-L, Li X-T, Cui Y, *et al.* Evaluation of dose reduction and image quality in chest CT using adaptive statistical iterative reconstruction with the same group of patients. Br J Radiol 2012;85:e906-11.
25. Xu J, Mahesh M, Tsui BMW. Is iterative reconstruction ready for

MDCT? J Am Coll Radiol 2009;6:274-6.

26. Thibault JB, Sauer KD, Bouman CA, Hsieh J. A three-dimensional statistical approach to improved image quality for multislice helical CT. Med Phys 2007;34:4526-44.
27. Sookpeng S, Martin CJ, Gentle DJ. Investigation of the influence of image reconstruction filters and scans parameters on operation of automatic tube current modulation systems for different CT scanners. Radiat Prot Dosimetry 2015;163:521-30.
28. Li J, Udayasankar UK, Toth TL, Seamans J, Small WC, Kalra MK. Automatic patient centering for MDCT: Effect on radiation dose. AJR Am J Roentgenol 2007;188:547-52.
29. Goo HW, Suh DS. The influences of tube voltage and scan direction on combined tube current modulation: A phantom study. Pediatr Radiol 2006;36:833-40.