



Extent of tube-current reduction using sinogram affirmed iterative reconstruction in pediatric computed tomography: phantom study

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Abstract

Background Iterative image reconstruction techniques can produce diagnostic-quality computed tomography (CT) images with lower radiation dose.

Objective To quantify the reduction in x-ray tube-current setting and optimize pediatric CT scans using different strengths of an iterative reconstruction technique.

Materials and methods The head, chest and abdomen regions of an anthropomorphic phantom representing a 5-year-old patient were scanned using standard CT protocols. Images were reconstructed using filtered back projection and different strengths of a sinogram affirmed iterative reconstruction technique. Repeated measurements of contrast-to-noise ratios in the lungs, bone and soft-tissue regions of the phantom were carried out. Maximum increase in contrast-to-noise ratio with iterative reconstruction strength was identified and a tube-current reduction factor was calculated. Head scans were repeated with reduced tube current and compared to filtered back projection images.

Results Iterative reconstruction strength of 3 for head and chest images and 4 for abdomen images were optimum, resulting in contrast-to-noise ratio increase of about 50%. A tube-current reduction factor of 1.2 for head images was calculated. Images of the head acquired using reduced tube-current showed similar contrast-to-noise ratio as images from filtered back projection with full tube current.

Conclusion Optimum strength of iterative reconstruction technique has been identified for head, chest and abdomen images. Reductions in tube current of 20%, resulting in similar radiation dose reduction, have been established.

Keywords Children · Computed tomography · Contrast-to-noise ratio · Iterative reconstruction technique · Tube-current reduction

Introduction

Computed tomography (CT) is the largest source of radiation even though it accounts for a relatively small percentage of all imaging modalities [1]. The use of CT has doubled in children younger than 5 years and tripled in children between 5 and 14 years of age in the United States between 1996 and 2005 [2, 3]. Multiple CT scans, over time, are likely to increase the risk of cancer, especially in children because of their higher radiosensitivity and longer life expectancy compared to adults

[4]. A number of techniques have been tried to reduce the radiation exposure while maintaining image quality or sometimes at slightly reduced image quality [1, 3, 4].

Many studies have assessed iterative reconstruction in reducing radiation dose and/or improving the image quality of CT scans compared to filtered back projection [1–13]. One such study [1] concluded that the image quality obtained in filtered back projection images can be maintained at lower tube voltage and tube current values when iterative reconstruction was used. The possibility of reducing radiation dose up to 50% while maintaining signal-to-noise ratio using adaptive statistical iterative reconstruction (ASIR; General Electric, Chicago, IL) and sinogram affirmed iterative reconstruction (SAFIRE; Siemens Healthcare, Erlangen, Germany) for children have also been reported [10–16]. Although signal-to-noise ratio is widely used as an image quality metric, it fails to represent how contrast can be affected by noise

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levels in the images. Using contrast-to-noise ratio to measure image quality will indicate how contrast and noise are affected by image acquisition and reconstruction parameters. However, the iterative reconstruction techniques used by different CT vendors differ in which parameters are available for the users to select and each of them varies in the degree of noise reduction [14]. The sinogram affirmed iterative reconstruction algorithm has five user selectable strengths in its application, with higher strengths having more noise reduction capability. Although higher levels of noise reduction can result in radiation dose reduction, they can also smooth the image and reduce the visibility of texture within tissues [14].

The objective of this phantom study was to assess the effects of different strengths of sinogram affirmed iterative reconstruction on image quality in comparison to filtered back projection and to identify the optimal strength of sinogram affirmed iterative reconstruction that would yield a balance between image quality and radiation dose in pediatric CT imaging.

Materials and methods

Study design

This study was carried out in two stages, first to establish the strength of sinogram affirmed iterative reconstruction for which optimum contrast-to-noise ratio was obtained and to identify a tube-current reduction factor, and the second to test the image quality with reduced tube-current scan. The head and body sections of a phantom representing a pediatric patient were scanned in a CT scanner. The images were reconstructed using filtered back projection and sinogram affirmed iterative reconstruction with strengths 1 to 5, respectively. Image quality was assessed by calculating contrast-to-noise ratio between bone region and soft-tissue regions using mean and standard deviation of CT numbers in the regions of interest in head images and body images. The strength of the sinogram affirmed iterative reconstruction that resulted in optimum contrast-to-noise ratio value was identified. Further scans of the head were performed with tube current reduced by a factor calculated by the square root of the ratio of optimum contrast-to-noise ratio with sinogram affirmed iterative reconstruction to the contrast-to-noise ratio with filtered back projection. The contrast-to-noise ratio values of the head images acquired using reduced tube current were compared with the contrast-to-noise ratio values of images acquired using the default tube current. All statistical analysis was carried out with $P < 0.05$ indicating the existence of significant difference among/ between groups.

Equipment

The ATOM dose verification phantom (Computerised Imaging Reference System, Virginia) representing a 5-year-old patient of 110 cm height, 19 kg weight and 14×17 cm of thorax dimensions was scanned using a 64-slice SOMATOM Definition Flash (Siemens Healthcare, Erlangen, Germany) CT scanner. The phantom is made of tissue-equivalent epoxy resins and offers tissue simulation for a wider range of x-ray energies from diagnostic and therapeutic procedures. All the bones in the phantom are homogeneous and are formulated to represent age-appropriate average bone composition.

Imaging procedure – Stage 1

In the first stage of the study, the head section of the phantom was scanned using the default “baby head” scan protocols of the CT scanner. In this protocol, 120 kV, 170 mA, 512 × 512 reconstruction matrix, 1-s tube rotation time and 3.6-mm reconstruction slice thickness were used. The chest and abdomen regions of the phantom were scanned as a single scan using the default pediatric body scan protocol of the scanner. The scan parameters were 80 kV, 113 mA, 512 × 512 matrix, 1-s tube rotation time and 4.8-mm reconstruction slice thickness. All dose reduction applications were turned off to achieve the required experimental conditions for this study. Image reconstruction was carried out using filtered back projection, representing image FBP, and sinogram affirmed iterative reconstruction with strengths 1 to 5, representing images IR₁ (iterative reconstruction₁), IR₂, IR₃, IR₄ and IR₅, respectively. Tube current values and image reconstruction filters used in this study are illustrated in Table 1. The volumetric CT dose index (CTDI_{vol}) was recorded from the scanner’s dose information.

Image analysis

Circular regions of interest, of approximately 200 to 500 pixels, were drawn in bone and soft-tissue regions in the head and abdomen images; bone, soft-tissue and lung regions of the chest images were drawn from these sections of the phantom. The mean CT number (Hounsfield units) and its standard deviation (σ) for each region of interest were recorded. In order to improve statistics, these measurements were repeated five times. The contrast-to-noise ratio (C) values were calculated using

$$C = \frac{|HU_T - HU_{Bkg}|}{\sigma_{Bkg}}$$

where T is target tissue and Bkg is the background. To calculate contrast-to-noise ratio in head and abdomen images, bone was considered as target; for the chest images, lung and bone

Table 1 Tube current values and image reconstruction kernels used in the study

Region	Reconstruction technique and filter used		Tube current used for filtered back projection, mA	Tube current used for strength 3 iterative reconstruction, mA
Head	Filtered back projection	H 30 f medium smooth	170	140
	Iterative reconstruction	J 30 f medium smooth		
Chest and abdomen	Filtered back projection	B 30 f medium smooth	113	
	Iterative reconstruction	I 30 f medium smooth		

were considered as targets separately, and soft tissue was considered background for all regions. For the chest images, the contrast-to-noise ratio was calculated as an average of the left and right lung regions. The strength of sinogram affirmed iterative reconstruction for which the contrast-to-noise ratio value ceased to increase significantly compared to the previous lower strength was identified as the optimum strength of sinogram affirmed iterative reconstruction technique for that procedure. A tube-current reduction factor (*M*) was defined as

$$M = \frac{\text{tube current}_{IR}}{\text{tube current}_{FBP}}$$

and calculated as

$$M = \sqrt{\frac{C_{\text{optimumSAFIRE}}}{C_{FBP}}}$$

The use of the equation above for *M* calculation is slightly different from using signal-to-noise ratio for the same calculation. In theory, the signal-to-noise ratio is the ratio of the amount of signal in a tissue on the image to the amount of noise present and is proportional to the square root of the radiation dose (and hence tube current). However, the contrast-to-noise ratio is calculated by taking the difference between the signal in the target tissue and the background tissue on the image and then dividing by the noise. Hence, contrast-to-noise ratio can be considered as the difference between two signal-to-noise ratios. Taking the difference between two signal-to-noise ratios increases the noise (uncertainty) present in the difference (contrast-to-noise ratio). All of this is correct if quantum noise is the dominant contributor to image noise. In clinical situations and when system noise is also included, contrast-to-noise ratio varies with tube current closer to the square root of tube current rather than the square of tube current. Hence, as a conservative method of dose reduction and image smoothing, *M* was calculated using the formula above.

Imaging procedure – Stage 2

In the second stage, the head region of the phantom was scanned again with tube current (used in the first stage) reduced

by *M* and all other scan parameters remaining unchanged. The images were reconstructed with strength 3 of sinogram affirmed iterative reconstruction. Two additional images of the head were also acquired, with 130 mA and 150 mA, respectively, to establish any changes in contrast-to-noise ratio with above and below the new tube-current established using *M*. The CTDI_{vol} was recorded from the scanner’s dose information. The contrast-to-noise ratio values for the same regions for the head images as in Stage 1 were calculated and compared with the original filtered back projection images.

Statistical analysis

All statistical analysis was carried out using Statistical Package for Social Sciences (SPSS; IBM Analytics, New York). One-way analysis of variance (ANOVA) was used to compare the contrast-to-noise ratio values obtained in Stage 1 of the study. Post hoc tests were carried out using Tamhane’s T2 statistics to compare pairs of images. The paired *t*-test was used to compare pairs of images acquired at different tube-current settings in Stage 2. For all statistical tests, the level of significance was set at 0.05.

Results

The first stage of this experiment showed a statistically significant (*P*<0.001) increase in contrast-to-noise ratio values in the images when sinogram affirmed iterative reconstruction was used with even the lowest strength compared to filtered back projection (Table 2). In the head and chest regions, contrast-to-noise ratio increased significantly as the strength of sinogram affirmed iterative reconstruction was increased from 1 to 3 and reached a plateau at strength 3 and remained unchanged for higher strengths. Post hoc tests indicate that images reconstructed using sinogram affirmed iterative reconstruction with strength 3, 4 and 5 resulted in similar (*P*>0.45) contrast-to-noise ratio values. In abdomen images, the contrast-to-noise ratio increased as the strength of iterative reconstruction was increased, probably showing a plateau beyond strength 4 (Table 2 and Fig. 1). The optimal strength of sinogram affirmed iterative reconstruction was identified as 3 for the head and chest images and as 4 for abdomen images. The increases

Table 2 Contrast-to-noise ratio mean±3 standard deviation for images reconstructed using filtered back projection (FBP) and different strengths of sinogram affirmed iterative reconstruction (IR)

Image	Contrast-to-noise ratio			
	Head	Chest-bone	Chest-lung	Abdomen
FBP	120 ± 6	143±3	124±3	87±3
IR1	138±6	155±3	134±3	105±3
IR2	142±3	183±6	160±6	121±3
IR3	168±6	230±3	201±6	134±3
IR4	171±6	232±6	201±9	159±3
IR5	170±3	230±3	201±3	161±3
P-value	<0.001	<0.001	<0.001	<0.001

in contrast-to-noise ratio at optimal sinogram affirmed iterative reconstruction strength compared to filtered back projection were 40% for head, 50% for abdomen and 60% for chest images. From these increases in contrast-to-noise ratio, M were calculated as 1.2 for head, 1.2 for abdomen and 1.3 for chest. All results of contrast-to-noise ratios are quoted as mean ±3× standard deviation throughout this paper.

The second stage of the study confirmed that the contrast-to-noise ratio (124±6) of the image acquired at 140 mA and reconstructed using sinogram affirmed iterative reconstruction strength 3 was similar to the contrast-to-noise ratio (120±6) of the image acquired at 170 mA and reconstructed using filtered back projection. Table 3 illustrates the contrast-to-noise ratio values for the images acquired at 130, 140 and 150 mA and reconstructed using sinogram affirmed iterative reconstruction

with strength 3 together with the contrast-to-noise ratio for the image acquired at 170 mA and reconstructed using filtered back projection. The CTDI_{vol} was reduced from 26.9 mGy at 170 mA to 21.4 mGy at 140 mA for the head scan, indicating approximately 20% reduction in patient dose.

Discussion

Iterative reconstruction techniques have been successfully introduced into CT image reconstruction and have been shown to produce similar quality images at lower radiation dose compared to filtered back projection. Several previous clinical studies [1, 3–5, 7–9, 11–13] have shown that iterative reconstruction technique leads to less image noise, allowing radiation dose reduction in pediatric CT imaging. The results of our study indicate that iterative reconstruction techniques improve contrast-to-noise ratio by a factor between 1.4 and 1.6, in agreement with results reported in other studies in terms of image quality [1, 3–9, 14]. As the strength of the iterative reconstruction was increased, the contrast-to-noise ratio increased until it reached a maximum value at strength 3 for head and chest CT images, leading to a possible M between 1.18 and 1.26. However, in the case of abdominal CT images, contrast-to-noise ratio reached a maximum at strength 4, leading to an M of 1.22. Increasing the strength of sinogram affirmed iterative reconstruction beyond 3 did not result in any further improvements in contrast-to-noise ratio and therefore limits any further dose reduction. Overall, a reduction in tube current of 20% for CT scans of the head, chest and abdomen of 5-year-old pediatric patients will not reduce the contrast-to-

Fig. 1 Variation of contrast-to-noise ratio with different strengths (0–5) of sinogram affirmed iterative reconstruction for images of different regions of the body

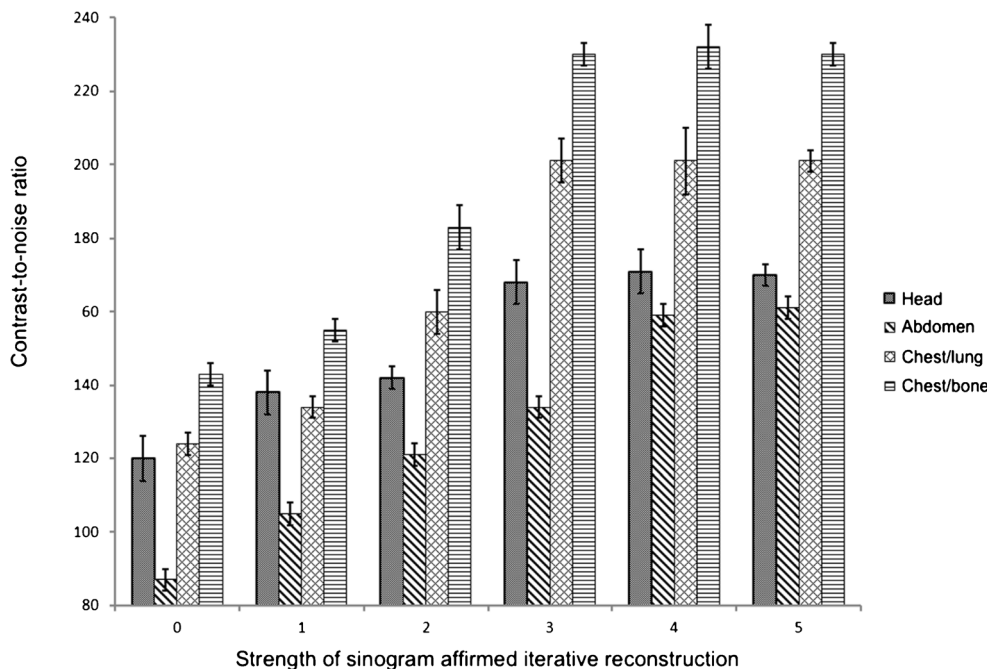


Table 3 Contrast-to-noise ratio mean \pm 3 standard deviations and volumetric CT dose index (CTDI_{vol}) for head CT acquired at tube-current setting reduced by tube-current reduction factor and reconstructed using

strength 3 of sinogram affirmed iterative reconstruction in comparison to full tube-current filtered back projection

	Contrast-to-noise ratio	T-test <i>P</i>	CTDI _{vol} (mGy)
170 mA filtered back projection	120 \pm 6	0.042	26.9
130 mA strength 3 of iterative reconstruction	110 \pm 3		19.5
170 mA filtered back projection	120 \pm 6	0.621	26.9
140 mA strength 3 of iterative reconstruction	124 \pm 6		21.4
170 mA filtered back projection	120 \pm 6	0.032	26.9
150 mA strength 3 of iterative reconstruction	144 \pm 6		24.0

noise ratio compared to the contrast-to-noise ratio of images obtained through filtered back projection at manufacturer recommended tube-current settings. This is in good agreement with dose reduction abilities of sinogram affirmed iterative reconstruction from previous studies [14].

The use of contrast-to-noise ratio as an image quality metric to evaluate the effects of iterative reconstruction is more comprehensive than using signal-to-noise ratio. In clinical situations, contrast-to-noise ratio is more relevant than signal-to-noise ratio for detecting low-contrast objects [9, 13]. The contrast-to-noise ratio refers to the ratio of difference in the signals between the object and the background to the noise in the background. In clinical situations, as this difference reduces, the detectability of the object also reduces, compounded by the amount of noise present. Hence, contrast-to-noise ratio measurements relate more to clinical image evaluations than signal-to-noise ratio. Although signal-to-noise ratio is directly related to the square root of the amount of radiation used for the imaging procedure, and hence the tube current, our findings indicate that changes in tube current calculated using the square root of contrast-to-noise ratio work well for patient dose reduction and contrast-to-noise ratio. This is confirmed by the method of M calculation and the results of the second stage of this study, although the confirmation is for head scans only. However, this finding may be extended to abdomen and chest CT scans once the results are confirmed in further studies, which are proposed. The attenuation of x-ray beams by the types of tissue present in the head region is different than the attenuation by the tissues in the chest and/or abdomen regions of patients. This variation in tissue attenuation could result in contrast-to-noise ratio variation with tube current in a slightly different manner. Excessive reduction of tube current during image acquisition and the use of excessive smoothing in image reconstruction to compensate for the increase in noise has the drawbacks of the plastic appearance of tissue without much texture, as reported by some radiologists [15]. Furthermore, calculating M using the square root of the contrast-to-noise ratio

reduces the radiation dose used for image acquisition by about 20% and therefore reduces the amount of smoothing carried out by sinogram affirmed iterative reconstruction. This helps reduce the plastic appearance of tissues and maintain tissue texture in the images.

Most CT scanners are equipped with several dose reduction mechanisms such as tube current modulation (CARE Dose 4D in Siemens scanners) and automatic tube voltage selection (CARE kV in Siemens scanners). These mechanisms allow the scanner to modulate tube current based on the total attenuation through different sections of the scanned regions and select optimal kV for the region being scanned. CARE Dose 4D and CARE kV are especially important in chest and abdomen scans, which involve higher beam penetration through the lungs. These two options were turned off during this study to isolate the effects of image reconstruction methods. When these dose reduction mechanisms are turned on in conjunction with sinogram affirmed iterative reconstruction strength 3, radiation dose reductions in excess of 20% can be achieved [11, 13].

This study had a few important limitations. The experiments were done on a single CT scanner using sinogram affirmed iterative reconstruction. Therefore, results may not be applicable to CT scanners from other manufacturer types or to other iterative reconstruction techniques. Moreover, the study was limited in the sense that the phantom had the disadvantage of not reflecting the actual composition and tissue density of human body organs. It provides objective and reproducible measurements, but results may not be transferred directly to clinical studies. So, the observations of the phantom study should be used only as a guide for relevant clinical situations. The diagnostic performance of iterative reconstruction utilizing the presented techniques needs to be evaluated in further patient studies.

Conclusion

Sinogram affirmed iterative reconstruction can produce images of better quality, at all iteration strengths, compared to filtered back projection using the same tube voltages and

currents for head, chest and abdomen scans in children. Optimum strength of sinogram affirmed iterative reconstruction maintains contrast-to-noise ratio at a 20% reduced radiation dose, compared to filtered back projection in pediatric head scans.

Compliance with ethical standards

Conflicts of interest None

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