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Original Research Article

Assessment of an iterative reconstruction algorithm (SAFIRE) on image quality in pediatric cardiac CT datasets

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Congenital heart disease

BACKGROUND: Pediatric cardiac patients often undergo repeat diagnostic testing, resulting in relatively high cumulative medical radiation exposure. Low-dose CT scanning techniques used to decrease radiation exposure may result in reduced image quality.

OBJECTIVE: This study evaluates a prototype iterative reconstruction algorithm, sinogram-affirmed iterative reconstruction (SAFIRE), to determine the effect on qualitative and quantitative measures of image quality in pediatric cardiac CT datasets, compared with a standard weighted filtered back projection (wFBP) algorithm.

METHODS: Seventy-four datasets obtained on a 128-slice dual-source CT system were evaluated for image quality using both the wFBP and the prototype iterative reconstruction algorithm. Contrast, noise, contrast-to-noise ratio, signal-to-noise ratio, and qualitative image quality were compared between groups. Data were analyzed as medians and 25th and 75th percentiles, and groups were compared with the use of the Wilcoxon singed-rank test or k sample equality of medians test.

RESULTS: There was a 34% decrease in noise, a 41% increase in contrast-to-noise ratio, and a 56% increase in signal-to-noise ratio in the prototype iterative reconstruction, compared with wFBP. All differences were statistically significant ($P < 0.001$). Qualitative measures of image noise and noise texture were also improved in the iterative reconstruction group ($P < 0.001$ for both). Diagnostic confidence was similar between reconstruction techniques. Median scan dose length product was 15.5 mGy · cm.

CONCLUSION: The prototype iterative reconstruction algorithm studied significantly reduces image noise and improves qualitative and quantitative measures of image quality in low-dose pediatric CT datasets, compared with standard wFBP.

Introduction

Pediatric patients have increased radiation sensitivity and appear to be at increased risk of long-term effects of radiation exposure from CT scanning. Radiation exposure at a young age is of particular concern because of the

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potential for an increased lifetime risk of malignancy.[1] Recent advances in CT technology provide innovative methods for decreasing radiation exposure. New second-generation dual-source high-pitch CT scanners have shown a reduction in radiation exposure compared with single-source older generation CT scanners that use standard pitch.[2–4] High-pitch scanners have been shown to be useful in the diagnosis of complex congenital heart disease, but the low-dose imaging techniques have increased image noise.[4,5] Iterative reconstruction (IR) techniques are a recent technologic advance that allows for maintained image quality with low-dose CT images.[6,7] These techniques have been shown to improve image quality in both adult and pediatric cardiac CT datasets.[8–12] Until recently, IR techniques were difficult to integrate into clinical workflow because of high computational demands and reconstruction times. However, advances in hardware and software now allow IR techniques to be used in routine clinical CT scanning. The purpose of this study was to evaluate the ability of a prototype of an IR algorithm, sonogram-affirmed iterative reconstruction (SAFIRE) to reduce image noise and to improve both qualitative and quantitative image quality compared with standard weighted filtered back projection (wFBP) reconstruction methods, while maintaining diagnostic confidence.

Methods

Study population and image acquisition

The study used clinically indicated pediatric cardiac CT scan datasets obtained on patients $\leq$18 years of age. The scans were obtained with a second-generation dual-source CT scanner (Definition Flash; Siemens Healthcare, Forchheim, Germany; temporal resolution = 75 milliseconds) from November 2009 through January 2011. The referral diagnosis for CT scanning was complex cardiac or coronary artery anatomy.

Prospective electrocardiogram (ECG)–triggered high-pitch helical scan mode was used for assessment of complex neonatal anatomy or for coronary artery anatomy when the heart rate was $\leq$60 beats/min (n = 60).[13] The prospective ECG-triggered axial scan mode with 40%–70% R-R cycle padding was used for coronary artery evaluation when the heart rate was >60 beats/min (n = 14).[13] Tube potential and tube current-time product were adjusted for body weight for all scan protocols. For patients weighing $\leq$65 kg 80 kVp was used, and for patients weighting $\geq$65 kg 100 kVp was used. No patient was scanned with 120 kVp. Reference tube currents were selected according to a locally developed algorithm that was based on the selected tube potential, patient age, and weight. An attenuation-based online tube current modulation of the reference tube current-time product was additionally used for all 60 patients scanned in the high-pitch scan mode and in 7 of those scanned in the prospectively ECG-triggered axial scan mode.

The scanner platform uses a standard 32-cm phantom for CT dose index volume (CTDIvol) estimates. The dose length product (DLP) was calculated by multiplying the scan length by the CTDIvol and was recorded from the scan protocol generated by the CT system.

IR algorithm

The SAFIRE algorithm is a raw data-based IR technique developed by Siemens Healthcare. After an initial reconstruction that used FBP, 2 different correction loops are introduced into the reconstruction process. The first loop, where data are re-projected into the raw data space (sinogram data) is used to correct imperfections in the original reconstruction and to remove or reduce artifacts from the data. This allows for additional validation of the images with the measurement data. The detected deviations are again reconstructed with the FBP yielding an updated image. This loop is then repeated a number of times; within each iteration a dynamic raw data-based noise model is applied, allowing for reduction of image noise without noticeable loss of sharpness. The second correction loop occurs in image space, where noise is removed from the image through a statistical optimization process. The corrected image is compared with the original, and the process is repeated a number of times, depending on the examination type, until the desired image is achieved.

Image reconstruction and analysis

All raw datasets were reconstructed with a standard wFBP method and the prototype IR algorithm. The B36 kernel is a sharper body kernel that was designed specifically for cardiac applications and is used routinely in wFBP. A corresponding kernel, I36, is the IR kernel that directly corresponds to the B36 and was used in the IR reconstructions. Both reconstructions were done from the same original dataset, and slice thickness, increment, and field of view were kept constant. The CT data files were transferred to a standard desktop workstation (syngo; Siemens Healthcare) for image analysis. Image noise, contrast, contrast-to-noise ratio (CNR), and signal-to-noise ratio (SNR) were calculated from an identical region of interest (ROI) in the primary anatomic region being evaluated for both datasets. ROI size was adjusted to the patient size and area of interest. The primary anatomic ROI was the right ventricle or pulmonary artery for those with tetralogy of Fallot or right-sided heart disease or anomaly, and either the left ventricle or the aorta for patients with left-sided heart disease or those requiring coronary artery imaging. Contrast and noise level were defined as the mean CT number within the ROI and the SD of the CT number, in Hounsfield units. CNR was defined as the difference between the mean CT number of the contrast-filled

Table 1 Quantitative image quality comparison between standard wFBP (B36) and SAFIRE (I36)

	wFBP (B36), median (25th–75th percentiles) (n = 74)	SAFIRE (I36), median (25th–75th percentiles) (n = 74)	Percentage change	P
Scan DLP, mGy · cm	15.5 (7–42)	15.5 (7–42)		
Contrast, HU	509.5 (429–633)	502.5 (425–625)	1	0.022
Noise, HU	72.5 (60–90)	47.5 (39–58)	34	<0.001
Contrast-to-noise ratio	5.55 (3.96–6.69)	7.80 (5.85–10.30)	41	<0.001
Signal-to-noise ratio	7.00 (5.34–8.78)	10.91 (7.95–13.62)	56	<0.001

structure and the mean CT number of the myocardial wall, which was divided by image noise. SNR was defined as mean CT number divided by image noise as previously described for cardiac datasets.[14] Qualitative image quality analysis was determined for all studies according to the European Image Quality Assessment. Factors assessed were sharpness (1 = very sharp; 2 = questionable; and 3 = noticeable blur, slice thickening), noise (1 = less than usual, 2 = optimal noise, and 3 = noise affects interpretation), noise texture (0 = no noticeable change; 1 = after changing window setting, no noticeable change; 2 = perceptible change; and 3 = change affects confident or blotchiness) and diagnostic confidence (1 = fully confident, 2 = probably confident, 3 = confident under limited conditions for visualization, and 4 = unacceptable).[15,16]

Descriptive statistics are summarized as medians and 25th and 75th percentiles for continuous variables because of skewed distributions, which were assessed for normality with the use of Schapiro–Wilk normality tests. Variables were assessed for statistical significance with the use of Wilcoxon matched pairs signed-rank test or k-sample equality of median tests. A P value <0.05 was considered significant and P values are 2-tailed when appropriate. All statistical calculations were done with Stata 11.2 (Stata Statistical Software, release 11; StataCorp, College Station, TX).

Results

Seventy-four pediatric CT image datasets were obtained from November 2009 to January 2011. Median patient age was 4.1 years (25th and 75th percentiles, 0.2–11.1 years). Sixty scans were performed in prospectively ECG-triggered high-pitch helical scan mode, and 14 scans were performed in the prospectively ECG-triggered axial scan mode. Median DLP for all scans was 15.5 mGy · cm, median DLP for the prospectively ECG-triggered high-pitch scan mode was 12 mGy · cm, and median DLP for the prospectively ECG-triggered scan mode was 58 mGy·cm. Contrast was 1% lower in the IR group than in the wFBP group (median, 502.5; 25th and 75th percentiles, 425–625) vs median, 509.5; 25th and 75th percentiles, 429–633; P = 0.022), but the effect was clinically insignificant. Noise was decreased, SNR and CNR were increased in scans reconstructed with IR compared with scans reconstructed with standard wFBP (Table 1). The qualitative assessment of image noise and noise texture were improved with IR (P < 0.001 for both), whereas image sharpness showed no change (P = 0.059). There was a 1-increment improvement in noise assessment in 63% of the scans, and no difference in 37% of scans. There was a 1-increment improvement in noise

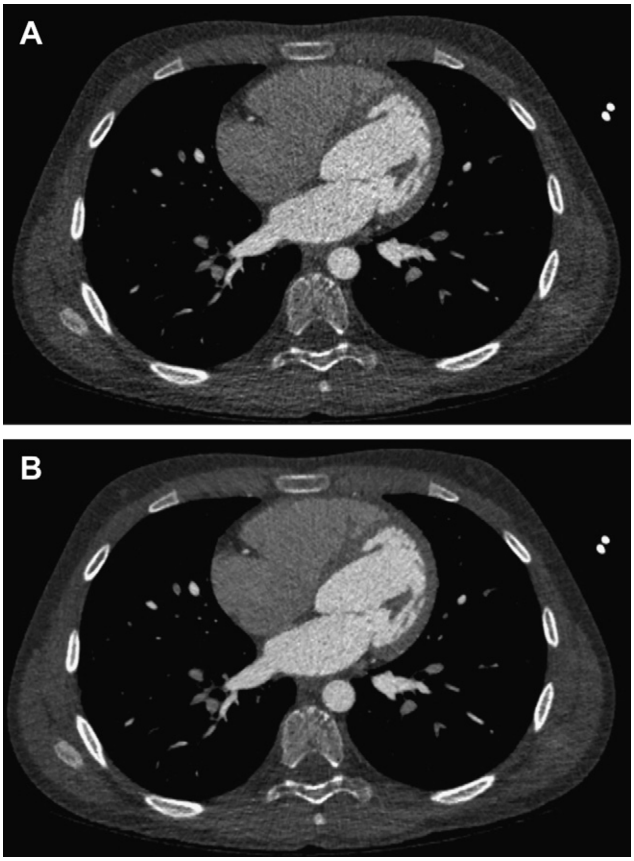

Figure 1 Shown is a four-chamber view from a scan obtained for evaluation of anomalous coronary artery in a 12-year-old patient. This was a prospective electrocardiogram-triggered high-pitch helical scan with a dose length product of 12 mGy · cm. Region of interest was placed in the body of the left ventricle. (**A**) Weighted filtered back projection (wFBP): contrast, 603; noise, 70; contrast-to-noise ratio (CNR), 6.7; signal-to-noise ratio (SNR), 8.6. (**B**) Sinogram-affirmed iterative reconstruction (SAFIRE): contrast, 603; noise, 45; CNR, 10.5; SNR, 13.6.

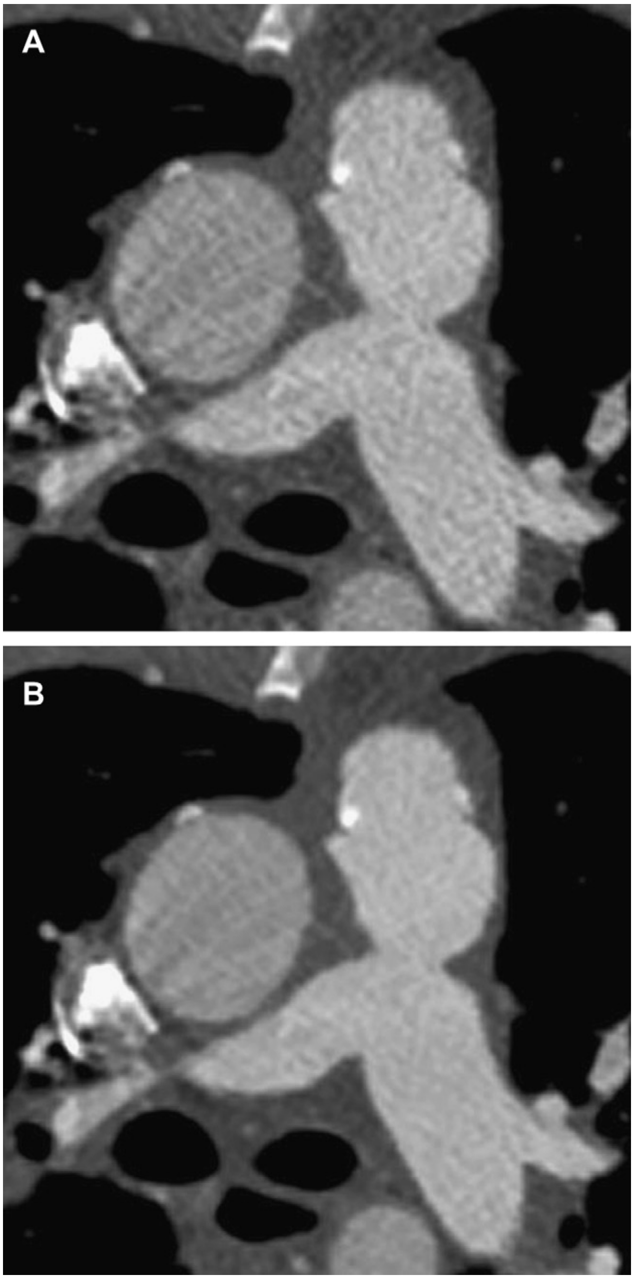

Figure 2 Shown is a right ventricular outflow tract (RVOT) conduit from a scan performed for evaluation of coronary artery anatomy and RVOT definition in a 6-year-old patient after the Ross procedure. This was a prospectively electrocardiogram-triggered axial scan with a dose length product of 41 mGy · cm. Region of interest was placed in the mid portion of the conduit. (**A**) Weighted filtered back projection (wFBP): contrast, 624; noise, 41; contrast-to-noise ratio (CNR), 13.5; signal-to-noise ratio (SNR), 15.2. (**B**) Sinogram-affirmed iterative reconstruction (SAFIRE): contrast, 624; noise, 27; CNR, 20; SNR, 23.

texture in 85% of the scans, a 2-increment improvement in 2% of the scans, and no improvement in 14% of the scans. A 1-increment improvement in sharpness was seen for 9% of the scans, whereas 90% of scans saw no difference and 1% saw a 1-increment decrease. Diagnostic confidence was similar between groups. The reduction in image noise and the improvement in the qualitative assessment of image noise with the IR algorithm were similar for both scan acquisition techniques and were similar for all levels of scanner output as measured in DLP. Figures 1 and 2 show representative images processed with the 2 different reconstruction algorithms.

Discussion

The purpose of this study was to evaluate the effect of a new IR algorithm on the image quality of pediatric cardiac CT datasets. The data show that noise, CNR, SNR, and qualitative assessment of noise and noise texture are significantly improved with this prototype IR algorithm (SAFIRE).

The clinical importance of reduced noise with this prototype IR algorithm lies in the potential for a systematic prospective decrease in CT dose with maintenance of image quality. In addition, its availability may give the physician confidence to use lower radiation doses with the knowledge that an unexpectedly noisy scan could subsequently be improved. The ultimate goal is to decrease the cumulative medical radiation exposure in the patient population with congenital cardiac disorders. Limitations in these data include the relatively small sample size. In addition, studies that compare IR algorithms with standard FBP cannot be appropriately blinded because of the obvious reduction of noise in the IR processed images.

In conclusion, noise reduction techniques will be useful to improve image quality in low-dose CT studies. In the future, the scanner output and radiation dose may prospectively be decreased to allow for dose reduction with maintained image quality in standard imaging protocols.

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