Experimental article – Maintaining image quality for paediatric chest CTs while lowering dose: FBP versus SAFIRE

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S A F I R E

FBP
CT
Paediatric patients
Chest
Image quality
Dose reduction

A B S T R A C T

Objectives: Children have a greater risk from radiation, per unit dose, due to increased radiosensitivity and longer life expectancies. It is of paramount importance to reduce the radiation dose received by children. This research concerns chest CT examinations on paediatric patients. The purpose of this study was to compare the image quality and the dose received from imaging with images reconstructed with filtered back projection (FBP) and five strengths of Sinogram-Affirmed Iterative Reconstruction (SAFIRE).
Methods: Using a multi-slice CT scanner, six series of images were taken of a paediatric phantom. Two kVp values (80 and 110), 3 mAs values (25, 50 and 100) and 2 slice thicknesses (1 mm and 3 mm) were used. All images were reconstructed with FBP and five strengths of SAFIRE. Ten observers evaluated visual image quality. Dose was measured using CT-Expo.
Results: FBP required a higher dose than all SAFIRE strengths to obtain the same image quality for sharpness and noise. For sharpness and contrast image quality ratings of 4, FBP required doses of 6.4 and 6.8 mSv respectively. SAFIRE 5 required doses of 3.4 and 4.3 mSv respectively. Clinical acceptance rate was improved by the higher voltage (110 kV) for all images in comparison to 80 kV, which required a higher dose for acceptable image quality. 3 mm images were typically better quality than 1 mm images.
Conclusion: SAFIRE 5 was optimal for dose reduction and image quality.

I N T R O D U C T I O N

Chest CTs are one of the most commonly used diagnostic imaging techniques for paediatric patients[1]. Unfortunately, radiation dose delivered during a CT examination is concerning, particularly for children, who have a greater risk per unit dose[2].

The radiosensitivity of children has been subject to debate and it is currently estimated that for 25% of cancer types, children are more susceptible than adults, and for 20% of tumour types the data is inconclusive[3]. It has been estimated that a one year old child is as much as ten times more susceptible to cancer than an adult[2]. It is therefore understandable that radiation dose has been a longstanding concern for paediatric patients, particularly when multiple scans are required.

Various imaging techniques can be used to reduce the radiation dose. Sinogram Affirmed Iterative Reconstruction (SAFIRE), developed by Siemens, is one of the possible new techniques. It is an alternative to conventional filtered back projection (FBP) and has been demonstrated to have significant dose reduction potential for adults. It also has the ability to decrease noise in the images[4]. Images are reconstructed using two correction loops; one occurs in image space to reduce noise, and one utilises sinogram data to correct imperfections[5].

Iterative reconstruction (IR) techniques typically offer a trade-off between dose and image quality. However, SAFIRE has been reported by numerous studies to have an equal visual image quality compared to FBP while reducing dose[6-8].

This study aims to assess the dose reduction potential of SAFIRE for paediatric chest CTs, as compared to FBP, while maintaining image quality. To quantify image quality, contrast, sharpness, clinical acceptance and image noise were analysed.

MATERIALS AND METHODS

CT protocol

An ATOM® Dosimetry Verification Phantom, modelled on the body of a 5 year old patient, was used for CT imaging[9]. Thorax dimensions were 14 x 17 cm and lung inserts with spherical targets were utilised. Images were taken with a Siemens SOMATOM® Perspective 128 multi-slice CT (MSCT) scanner at 110 kV and 80 kV, with mAs values of 25, 50 and 100. The images were reconstructed with a slice thickness of 1 mm and 3 mm for each mAs value. We chose to use images reconstructed with a soft kernel, as this kernel can increase the low-contrast detectability. FBP images were reconstructed using the B31s kernel, and SAFIRE images using the I31s filter[10].

SAFIRE has five strengths, with SAFIRE 5 being the smoothest. The number of interactions is not dependable on the strength chosen. Each strength has different levels of noise reduction and can create different textures[5]. To ensure that SAFIRE's potential was fully tested, all five strengths were used for reconstruction in this research. Images were also reconstructed using FBP for comparison purposes. This yielded 72 images for analysis in total.

The imaging and reconstruction processes were performed by Siemens, who then provided the images for analysis.

Visual analysis

Ten observers were chosen to review the images, nine of which were graduate or qualified radiographers with varying levels of experience. One observer was a medical physicist.

Images were rated visually based on sharpness, contrast and noise. Each image was reviewed individually and the observers rated contrast and sharpness on a 5 point Likert scale (1 = poor, 2 = fair, 3 = moderate, 4 = good, 5 = extreme). Noise was rated on a 3 point scale (1 = noise affects the interpretation, 2 = acceptable noise, 3 = very little noise). Observers were also asked whether they deemed the image clinically acceptable for diagnostic purposes. Images were displayed using ViewDex, on a 30" monitor with a resolution of 1440 x 900, for CT images with a matrix of 512 x 512.

Each image was randomised and rated individually; they were not compared with each other. This was done in hopes of achieving a quality score for each image while minimising bias. The observers rated each image twice, in separate sessions.

Dose analysis

Dose was measured using CT-Expo v2.3.1, using a 'child' age group and a scan range of 22 to 44 cm. The scanner model was input as Siemens and scanner as 'perspective series'. The mode was 'spiral mode'. Dose was calculated for each combination of mAs and kV.

Parameters were entered into CT-Expo (kV, mAs, slice thickness) and effective dose (mSv), organ dose, CT dose index (CTDI) and dose length product (DLP) were calculated using the ICRP 103 method.

Statistical analysis data

Statistical analysis was performed using SPSS. Differences between techniques in sharpness and contrast were analysed by means of linear regression analysis. A p-value of less than 0.05 was considered to be statistically significant. The B coefficients (as shown in Tables 1 and 2) were used to create formulae for calculating dose for specific image qualities and visa versa. The equation used for calculation dose was as follows:

$$\mathbf{Dose} = [\mathbf{IQ} - (B_1 \times \mathbf{Model}_1) - (B_2 \times \mathbf{Model}_2) - (B_3 \times \mathbf{Model}_3) - (B_4 \times \mathbf{Model}_4) - (B_5 \times \mathbf{Model}_5) - \mathbf{constant}] / B_{\mathrm{Dose}}$$

Where model1 was SAFIRE 1, model2 was SAFIRE 2 etc, and B1 was the B coefficient corresponding to SAFIRE 1 etc. Dose could be calculated using image quality.

$$\textbf{Image Quality (IQ)} = (\mathbf{Dose} \times B_{\mathrm{Dose}}) + (B_1 \times \mathbf{Model}_1) + (B_2 \times \mathbf{Model}_2) + (B_3 \times \mathbf{Model}_3) + (B_4 \times \mathbf{Model}_4) + (B_5 \times \mathbf{Model}_5) + \mathbf{constant}$$

Image noise and clinical acceptability were evaluated using acceptance percentage. Scores of 2 and 3 were counted as acceptable for noise.

Table 1: Statistical significance of SAFIRE for sharpness

Model	Unstandardized Coefficient (B)	Sig.
(Constant)	2,509	<,001
Dose	,234	<,001
SAFIRE 1	,221	,003
SAFIRE 2	,292	<,001
SAFIRE 3	,404	<,001
SAFIRE 4	,412	<,001
SAFIRE 5	,450	<,001

Model	Unstandardized Coefficient (B)	Sig.
(Constant)	2,787	<,001
Dose	,178	<,001
SAFIRE 1	,192	,004
SAFIRE 2	,262	<,001
SAFIRE 3	,383	<,001
SAFIRE 4	,446	<,001
SAFIRE 5	,600	<,001

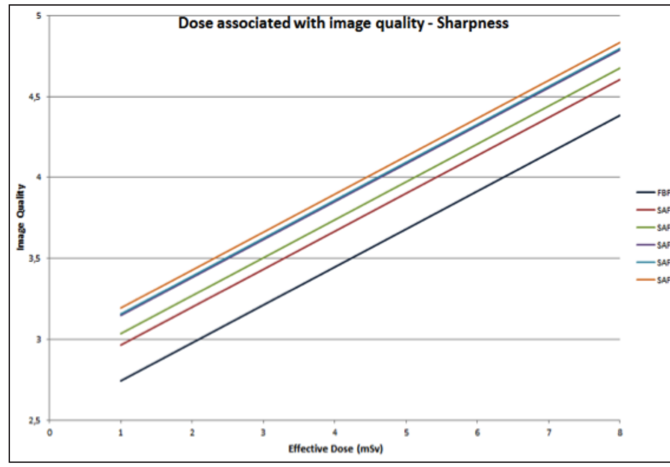

Figure 1: linear regression for sharpness for SAFIRE and FBP.

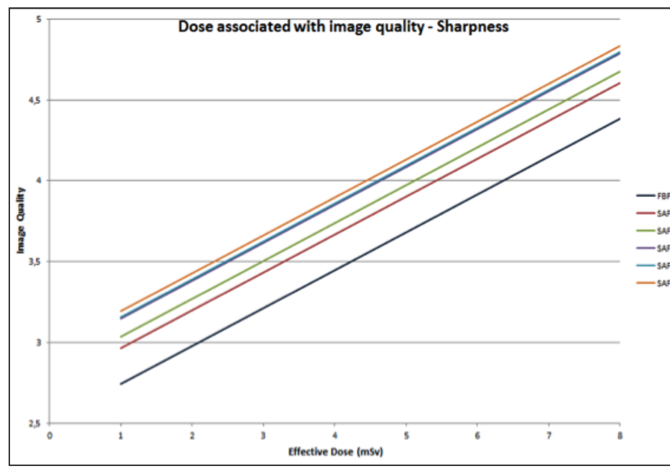

Figure 2: linear regression for contrast for SAFIRE and FBP.

RESULTS

Image sharpness and contrast

Linear regression was calculated with respect to both sharpness and contrast. The outcomes of the linear regression are shown in Figures 1 and 2.

An equation to calculate the effect of the dose on image quality for FBP- and all of the SAFIRE-reconstructions was formed using the B-value coefficients. This correlation is shown by Figures 1 and 2. It can be seen that FBP always required a higher dose to achieve the same image quality as SAFIRE. Relating to contrast, an image quality score of 4 required a dose of 3.4 mSv for SAFIRE 5 reconstruction. FBP required a dose of 6.8 mSv. For sharpness-related image quality, a rating of 4 using SAFIRE 5 required 4.4 mSv whereas FBP needed 6.4 mSv.

Table 3 shows the dose reduction potential while maintaining an image quality of 4 for all reconstruction techniques.

Image noise

The visual ratings regarding image noise are shown in Table 4. Percentages include noise ratings of average and less than average (scores of 2 and 3). The table shows that for 80 kV and 1.2 mSv, 100% of observers evaluated SAFIRE 5 images to have acceptable noise levels. In comparison, only 55% of observers rated FBP reconstructed images as acceptable. It can also be seen that slice thickness generally affects the amount of noise in the images. When comparing FBP images with 80 kV and 2.4 mSv, the acceptance level raised by 45% between 1 and 3 mm.

110 kV greatly improves noise ratings in comparison to 80 kV. The difference between FBP and all strengths of SAFIRE is almost non-existent at this voltage. All 3 mm images were rated to have acceptable noise by at least 90% of observers.

Clinical acceptability

The visual ratings regarding the clinical acceptability are shown in table 5.

It appears that SAFIRE and FBP are equally accepted at 110 kV with doses of 3 and 6 mSv. For 80 kV, SAFIRE consistently has a higher percentage of acceptance than FBP, particularly for the higher doses. Higher strengths of SAFIRE are also generally more clinically acceptable for lower doses, but SAFIRE strengths 2, 3 and 4 also receive good scores for slightly higher doses.

Table 3: *Dose reduction (mSv) for SAFIRE strengths compared with FBP*

		SAF1	SAF2	SAF3	SAF4	SAF5	FBP
Sharpness	Dose	5,42	5,12	4,64	4,60	4,44	6,36
	Dose reduction (mSv)	0,94	1,24	1,72	1,76	1,92	0
Contrast	Dose (mSv)	5,74	5,34	4,66	4,31	3,44	6,81
	Dose reduction (mSv)	1.08	1,47	2,15	2,5	3,37	0

Table 4: *Percentage of observers who scored noise as acceptable or better*

	80 kV 1mm			80 kV 3mm			110kV 1mm			110kV 3mm		
	0.6mSv	1.2mSv	2.4 mSv	0.6 mSv	1.2mSv	2.4mSv	1.5mSv	3mSv	6mSv	1.5mSv	3mSv	6mSv
Acceptable and above noise (%)	%	%	%	%	%	%	%	%	%	%	%	%
FBP	0	25	55	25	75	100	50	85	100	95	95	95
SAF1	5	45	80	55	80	100	75	95	95	95	100	95
SAF2	15	65	95	55	85	100	75	90	95	100	100	95
SAF3	0	70	100	80	95	100	90	100	95	100	95	100
SAF4	35	95	100	80	90	100	95	100	100	100	95	95
SAF5	40	100	100	95	95	100	100	95	95	100	90	95

Table 5: *Percentage of observers who scored images as clinically acceptable*

	80 kV 1mm			80 kV 3mm			110kV 1mm			110kV 3mm		
	0.6mSv	1.2mSv	2.4 mSv	0.6 mSv	1.2mSv	2.4mSv	1.5mSv	3mSv	6mSv	1.5mSv	3mSv	6mSv
Clinical acceptance (%)	%	%	%	%	%	%	%	%	%	%	%	%
FBP	5	35	40	15	50	85	55	85	100	65	80	100
SAF1	15	60	65	15	50	90	60	100	100	80	80	100
SAF2	15	60	80	30	65	90	70	95	100	85	85	95
SAF3	15	55	90	50	65	85	85	95	100	80	80	100
SAF4	35	70	90	55	60	90	80	100	95	75	75	95
SAF5	35	90	90	65	70	90	85	100	100	75	75	95

DISCUSSION

It is suggested that SAFIRE 5 can provide a dose reduction of 50% in comparison to FBP, as rated according to image contrast. For image sharpness, the dose reduction is smaller but still significant and is approximately 30%.

Literature suggests that SAFIRE strengths 3 and 4 are best for image quality[11-13]. Our results suggest that SAFIRE 5 is optimal for dose reduction while maintaining image quality. The reason for SAFIRE 5 being optimal could be due to the phantom being child-sized. Research is limited regarding all SAFIRE strengths for paediatric patients and so it is difficult to compare.

Dose reductions for all SAFIRE strengths are shown in Table 3. It shows that dose can be reduced by 0.9 to 3.4 mSv, depending on the strength of SAFIRE used. SAFIRE 5 always has the greatest dose reduction, and also has the best rated clinical acceptance for almost all doses.

Previous studies suggested a potential dose reduction from 15 to 85% [14], depending on parameters, patient size and SAFIRE strength. However, most studies tended to fall in the region of around 50%[6,12-13,15-17]. Our estimated dose reduction for SAFIRE 5 is approximately 50%, which agrees with other studies.

A linear model was used for data analysis due to measured dose values suggesting a linear trend. For 80 kV it was found that the effective doses were 2.4, 1.2 and 0.6 mSv for 100, 50 and 25 mAs respectively; this shows that although the overall trend might not be linear, for the window of data we were considering it was almost perfectly linear. This trend continued up to our highest measured dose value of 6.1 mSv. In reality, the dose and image quality relationship is not linear, it is asymptotic.

Clinical acceptability was higher for 3 mm image slices than for 1 mm slices, and increased as the SAFIRE strength increased. The higher voltage also had better acceptability overall. 3 mm images contain more data than 1 mm images which allows for greater noise reduction during reconstruction. This might not be true for a clinical CT scan because there is a possibility that pathologies and anatomical structures might be overlooked.

For Tables 4 and 5, percentages that end with 5, for example 85% and 95%, suggest that one or more observers rated images differently during the test and re-test. This could be due to user error or could be a sign of decreased intra-observer reliability. Observers may have rated images differently the second time due to being more acquainted with the image rating procedure. Further research is suggested to investigate this phenomenon.

Noise decreased with increasing dose, and there was less noise in the 110 kV datasets than in the 80 kV images. All of the SAFIRE strengths had acceptable levels of noise for doses of 2.4 mSv and above. For the lower doses at 80 kV, the higher strengths of SAFIRE performed better. SAFIRE 5 received a 90% acceptable noise rating for every dose except 0.6 mSv at 80 kV with 1 mm thickness. SAFIRE 4 was also suitable for most doses, and received a percentage score of 90 and above, excluding 0.6 mSv at 80 kV for 1 mm and 3 mm thicknesses.

Objective data was analysed and then disregarded, based on the fact that results were inconsistent. This is potentially due to the field of view in the received images differing. Changes in the field of view led to the ROI moving and changing in size. This lead to different amount of pixels being included which caused anomalous data.

Visual noise rating was evaluated using a three point scale. Linear regression is invalid for a three point scale, meaning that it could not be used during the analysis of signal to noise ratio. It is expected that dose reduction could be calculated if the linear regression was used.

Further research could utilise more observers, or observers with a higher level of experience. Also, real clinical images could be utilised instead of a phantom; lack of anatomical structures makes the evaluation of the images less realistic.

CONCLUSION

Dose reduction increased with higher SAFIRE strengths. SAFIRE 5 was optimal and estimated to have dose reductions of approximately 30% and 50% relating to sharpness and contrast image quality respectively. SAFIRE was most effective for dose reduction at lower kV.

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