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Reducing the radiation dose of pediatric paranasal sinus CT using an ultralow tube voltage (70 kVp) combined with iterative reconstruction

Feasibility and image quality

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Abstract

Background: As the gold standard for imaging sinus disease, the main disadvantage of computed tomography (CT) of the pediatric paranasal sinus is radiation exposure. Because of this, 1 protocol for CT should reduce radiation dose while maintaining image quality. The aim of this study is to evaluate the image quality of dose-reduced paranasal sinus computed tomography (CT) using an ultralow tube voltage (70 kVp) combined with iterative reconstruction (IR) in children.

Methods: CT scans of the paranasal sinus were performed using different protocols [70 kVp protocols with IR, Group A, n=80; 80 kVp protocols with a filtered back projection algorithm, Group B, n=80] in 160 pediatric patients. Then, the volume-weighted CT dose index, dose-length product, and effective dose were estimated. Image noise, the signal-to-noise ratio and the diagnostic image quality were also evaluated.

Results: For the radiation dose, the volume-weighted CT dose index, dose-length product and effective dose values were significantly lower for the 70 kVp protocols than for the 80 kVp protocols ($P < .001$). Compared with the 80 kVp protocols, the 70 kVp protocols had significantly higher levels of image noise ($P = .001$) and a lower signal-to-noise ratio ($P = .002$). No significant difference in the overall subjective image quality grades was observed between these 2 groups ($P = .098$).

Conclusion: The ultralow tube voltage (70 kVp) technique combined with IR enabled a significant dose reduction in CT examinations performed in the pediatric paranasal sinus while maintaining diagnostic image quality with clinically acceptable image noise.

Abbreviations: CTDIvol = volume-weighted CT dose index, DLP = dose-length product, ED = effective dose, FBP = filter back projection, IR = iterative reconstruction, SNR = signal-to-noise ratio.

Keywords: dual-source computed tomography, image quality, iterative reconstruction, paranasal sinuses, radiation dose

1. Introduction

Sinusitis is a common pediatric disease associated with 5% to 10% of the upper respiratory tract infections in children.[1] Non-enhanced multidetector computed tomography (CT) is the gold standard for the diagnosis of paranasal sinusitis.[2,3] Its high spatial resolution and ability to show the contrast between bone and soft tissue allow CT of the paranasal sinus to provide a wealth of relevant information.[2,4] However, the main disadvantage of CT is radiation exposure, which is especially important for children, who are 10 times more sensitive to radiation than adults.[5,6] Because of the proximity to radiation-sensitive organs (such as the lens of the eye and the thyroid gland), the radiation dose must be considered when planning a CT scan of the paranasal sinus, as these organs are exposed to direct or scattered radiation.[7–10]

Second-generation dual-source CT (DSCT) systems allow CT examinations to be performed at voltages ranging from 140 kVp to as low as 70 kVp and provide a new perspective in low-dose imaging as 80 kVp is the lowest tube potential available in previous systems. Over the years, the ultralow-dose 70 kVp protocol has been widely used for pediatric chest CT scans.[11–13] However, there are few reports about the application of this CT technique to evaluate the paranasal sinus in children.

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Further tube voltage reduction is impeded by increasing image noise. In recent years, many studies have confirmed that, compared with traditional filter back projection, iterative reconstruction (IR) can reduce image noise and radiation doses without a loss in diagnostic image quality.[7,14,15] The purpose of this study was to evaluate the image quality and the radiation dose applied in protocol in which ultralow tube voltage (70 kVp) is combined with the IR in children.

2. Methods

2.1. Patient selection

This prospective study was approved by the institutional ethics review committee of Suzhou Ninth People's Hospital and informed consent was obtained from the guardians of all the children.

2.2. CT examinations

All scans were performed on a DSCT (SOMATOM Definition Flash, Siemens, Forchhiem, Germany) with patients in the supine position. The ultralow-dose protocol performed at 70 kVp was used in 80 children (38 boys and 42 girls; age range: 3 to 16 years [mean age: 8.7 years], classified as Group A). Transverse images were reconstructed with Sinogram Affirmed IR, which has 5 levels, the 3rd of which was selected for this reconstruction. The in-house low-dose protocol was performed at 80 kVp in another 80 children (44 boys and 36 girls; age range: 5–16 years [mean age: 9.1 years], classified as Group B), and the resulting transverse images were reconstructed with conventional filter back projection. Details are shown in Table 1.

The patients were placed in the supine position, and the scans were performed from the roof of the frontal sinus to the maxillary sinus in a craniocaudal order. To reduce tooth artefacts, the patient's upper jaw was aligned with the gantry. The following multiplanar reconstructions were made from the raw data: 2-mm axial, 2-mm coronal, and 2-mm sagittal images (with separate kernels for bone and soft tissue).

2.3. Radiation dose estimates

For each examination, the dose-length product (DLP, mGy·cm) and the volume-weighted CT dose index (CTDIvol, mGy) were automatically recorded and uploaded to the PACS system. To calculate the effective dose (ED, mSv), the DLP was multiplied by the age-related conversion factor κ (0–1.0 years, 0.011; 1.1–5 years, 0.0067; 5.1–10 years, 0.0040; and 10.1–18 years, 0.0032) as follows: $ED = DLP \times \kappa$.[16]

Table 1

Scan parameters for the 2 protocols.

Protocol	Group A	Group B
Tube voltage (kVp)	70	80
Tube current-time product (effect mAs)	40	40
Pitch	1.5	1.5
Detector collimation (mm)	32 × 1.2	32 × 1.2
Rotation time (s)	0.5	0.5
Slice thickness (mm)	2	2
Reconstruction	SAFIRE	FBP

FBP = filter back projection, SAFIRE = Sinogram Affirmed Iterative Reconstruction.

2.4. Image quality

All image sets were anonymized and transferred to a clinical PACS workstation (Centricity 4.1, General Electric Healthcare, Dornstadt, Germany) for analysis. Two pediatric radiologists with more than five years of experience evaluated image quality in a blinded manner on a workstation. Observers were allowed to adjust the window width and level according to their own viewing habits.

To analyse the objective image quality, we applied a circular region of interest with a 4 mm diameter to measure the attenuation in the vitreous body. The standard deviation (SD) of the vitreous body was set as the background noise. After bilateral symmetrical measurements, the mean results were recorded, and based on these results, the signal-to-noise ratio (SNR) was obtained using the following equation: SNR = attenuation/background noise.

To analyse the subjective image quality, we referred to a 5-point scale (5 = excellent image quality/minimum noise, 4 = good image quality/low noise, 3 = medium image quality/moderate noise, 2 = diagnosis doubtful/high noise, and 1 = non-diagnostic/unacceptable noise) to evaluate the general image impression of the background noise and the teeth and motion artefacts of patients. The same scale was used for the differentiation of common anatomical landmarks of the paranasal sinuses (such as the ostiomeatal complex, the septal branches of the ethmoidal sinus, and the courses of the internal carotid artery and the optical nerve in the sphenoidal sinus).[17] In particular, the differentiation of the tissue near the orbital cavity and retrobulbar space (such as the eye muscles, optic nerves and mastoid cells of the temporal bone) required special consideration. Typical CT signs of localized/circular mucosal swelling or the presence of sinusoidal fluid indicated the presence of possible sinusitis.

2.5. Statistical analysis

All the data sets were analysed using SPSS16.0 (IBM Corp., New York, NY; formerly SPSS Inc., Chicago, IL). The radiation dose and objective image quality were recorded in detail and are expressed as the means ± SD. The radiation dose and objective image quality were evaluated using an independent samples *t*-test. Image scores were tested using nonparametric methods (Mann-Whitney *U* test). Interobserver agreement in the subjective image quality ratings was assessed by kappa analysis (k: 0.81–1.0, excellent; k: 0.61–0.80, good, k: 0.41–0.60, moderate; k: 0.21–0.40, fair; $k < 0.20$, slight agreement). A *P*-value of $< .05$ was considered to indicate statistical significance.

3. Results

3.1. Patient characteristics

No significant differences ($P > .05$) in the sex distribution or age could be observed between the 2 groups.

3.2. Radiation dose estimation

The mean CTDIvol, DLP, and ED values were 1.01 mGy, 13.75 mGycm and 0.051 mSv, respectively, in Group A and 1.56 mGy, 21.76 mGycm and 0.085 mSv, respectively, in Group B. Compared with Group B, in Group A, the CTDIvol, DLP and ED of the ultralow tube voltage group were lower by 35%, 37% and 40%, respectively ($P < .001$) (Table 2).

Table 2

Radiation dose in the ultralow-dose protocol (Group A) and the regular low dose protocol (Group B).

Parameter	Group A	Group B	*P*-value
CTDIvol (mGy)	1.01±0.03	1.56±0.02	<.001
DLP (mGycm)	13.75±1.63	21.76±1.91	<.001
ED (mSv)	0.051±0.04	0.085±0.05	<.001

CTDIvol=volume-weighted CT dose index, DLP=dose-length product, ED=effective dose.

3.3. Objective image quality

The measured image noise was higher in Group A than in Group B ($P=.001$), and the SNR was lower in Group A than in Group B ($P=.002$). The results of the objective image quality evaluation are shown in Table 3.

3.4. Subjective image quality

The diagnostic image quality of the 2 scan protocols is shown in Figure 1. No study was considered to be Grade 1 or 2 in either group. The frequency distribution of the subjective image quality scores for the pediatric paranasal sinus is displayed in Table 4. No significant difference in the frequency distribution of the image quality scores was observed between the 2 groups ($P=.098$). The interobserver agreement was excellent for Group A (k=0.831) and Group B (k=0.860). The image quality after evaluating particular anatomical landmarks was very similar for both groups (see Table 5).

4. Discussion

CT is a vital and increasingly used imaging technique in the pediatric population due to its importance and accuracy in diagnosis.[18] Adolescence is a critical period of growth and development during which children are sensitive to radiation damage, especially the lens of the eye.[19] The weighting of these 2 facts is the basis of the "as low as reasonably achievable" (ALARA) principle in pediatric CT.[3,7,20] Therefore, reducing the radiation dose of CT scans in the paranasal sinus is of great significance.

Various methods can be used to reduce the radiation dose, eg, increasing the pitch,[21,22] IR techniques,[7,14,15] and cone-beam CT.[23] Previous studies showed that promising results can be achieved by different CT dose reduction strategies: Abul-Kasim et al reported a dose reduction in the DLP of 20 mGy·cm and 41 mGy·cm when using an 80 kVp protocol (17 and 33 mAs) in a phantom study.[24] Also with an 80-kVp protocol, Mulkens et al concluded that a tube current-time product of 15 mAs still achieved sufficient image quality for an accurate diagnosis of the pediatric sinus.[25] Additionally, Schulz et al achieved a dose reduction down to a DLP of 37 mGy·cm with a 100 kVp protocol performed at 25 mAs.[26] At present, the ultralow-dose 70 kVp protocol is widely used for pediatric chest CT scans.[11–13] The sinuses, which are mainly composed of bone, air, and soft tissue, have good natural contrast, and low-dose CT scans in this region

Table 3

Objective image quality in the ultralow-dose protocol (Group A) and the regular low-dose protocol (Group B).

	Reconstruction	Attenuation (HU)	Noise (HU)	SNR
Group A	SAFIRE	39.33±8.21	34.86±5.04	1.16±0.31
Group B	FBP	31.34±5.00	20.85±3.10	1.53±0.31
P-value		.002	.001	.002

FBP=filter back projection, SAFIRE=Sinogram Affirmed Iterative Reconstruction, SNR=signal-to-noise ratio.

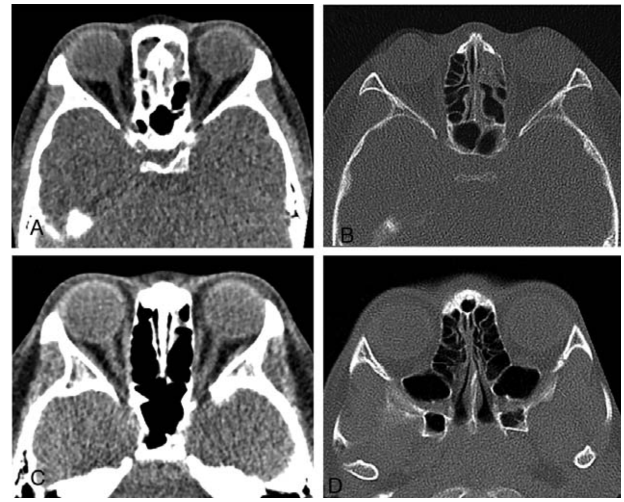

Figure 1. A-B Axial images of an 8-year-old boy examined using the ultralow-dose protocol at 70 kVp combined with SAFIRE showing the presence of sinusitis with mucosa swelling in the bilateral ethmoid sinus. C, D Axial images of a 12-year-old boy examined using the regular low-dose protocol at 80 kVp combined with FBP showing the presence of sinusitis with mucosal swelling in the left ethmoid sinus.

Table 4

Subjective image quality evaluation of paediatric paranasal sinus in the ultralow-dose protocol (Group A) and the regular low dose protocol (Group B).

Readers	Group A	Group B	*P*-value
Reader 1			.175
5	34 (42.5%)	40 (50%)	
4	38 (47.5%)	38 (47.5%)	
3	8 (10%)	2 (2.5%)	
Reader 2			.102
5	30 (37.5%)	38 (47.5%)	
4	40 (50%)	38 (47.5%)	
3	10 (12.5%)	4 (5%)	
Both readers			.098
5	32 (40%)	40 (50%)	
4	40 (50%)	38 (47.5%)	
3	8 (10%)	2 (2.5%)	
Kappa value	0.831	0.860	

Table 5

The image quality scores used to evaluate particular anatomical landmarks in the ultralow-dose protocol (Group A) and the regular low-dose protocol (Group B).

Group	Group A	Group B
General image quality	3.6	3.9
Ostiomeatal complex	3.7	4.0
Ethmoidal septal branches	3.8	4.1
Carotid artery and optical nerve in sphenoidal sinus	3.9	4.1
Orbital cavity and retrobulbus space	3.8	4.2
Mastoid cells	3.9	4.1

Image scores of defined anatomical structures: 1=poor, 5=excellent.

have received the same attention as those performed in the lungs. B. Bodelle et al indicated that the ultralow-dose 70 kVp protocol still provides a balanced compromise between dose reduction and diagnostic image quality.[27] In the present study, we used an ultralow-dose 70 kVp protocol to evaluate the radiation dose and image quality of CT examinations of the pediatric paranasal sinus. The average dose was 0.051 mSv (average DLP: 13.75 mGy·cm).

With regard for the ultralow-dose technique, the image quality obtained for the identification of anatomical landmarks and the presence of sinusitis was acceptable with a good-to-medium score. One reason for the loss in subjective image quality in the 70 kVp images was an overall increase in noise. To ensure image quality, in our study, we adopted an IR that effectively reduced image noise and ensured image quality.[7,14,15] Although in our study the SNR was still significantly lower for the 70-kVp CT protocol than for the 80-kVp CT protocol, evaluation of the subjective quality of the images between the 2 groups did not reveal a significant difference, and both met the diagnostic requirements. As Schulz et al pointed out, using a wide window setting and reconstructing a thicker portion (2 mm adjacent image) from a submillimetre collimated MDCT scan markedly reduced the subjective noise impression to an acceptable level.[21]

When the 70 kVp CT protocol was adopted, the estimated ED was 0.051 mSv, which was within the average ED range of radiography (0.02 to 0.09 mSv), but the 70 kVp CT protocol provided more valuable information.[5,24,25,28,29] Therefore, the present ultralow-dose technique may be especially beneficial for CT imaging of suspected sinusitis in children.

However, there are still some limitations to our study. First, the purpose of this study was to compare ultralow-dose scans performed at 70 kVp with low-dose scans performed at 80 kVp, and we excluded other tube voltage protocols. Second, future studies should use more detailed radiation groups based on the age of the children. Third, when controlling the amount of noise suppression with the Sinogram Affirmed Iterative Reconstruction software in our study, we did not compare the 5 different reconstruction strengths (I = weakest to V = strongest).

5. Conclusions

In conclusion, the results of this study suggest that the ultralow tube voltage (70 kVp) technique enables a significant dose reduction when imaging the paranasal sinus in pediatric patients, with only slightly reduced image quality. The proposed ultralow-dose CT protocol can be used as a screening method for inflammation of the pediatric paranasal sinus.

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