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FULL PAPER

Evaluation of chest CT scan in low-weight children with ultralow tube voltage (70 kVp) combined with Flash scan technique

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Objective: To assess radiation dose and image quality of chest CT examinations in low-weight children acquired at ultralow tube voltage (70 kVp) combined with Flash scan technique.

Materials and methods: 30 consecutive paediatric patients (weight <20 kg) required non-contrast chest CT at 70 kVp with Flash scan mode (Group A). 30 patients for paediatric standard 80-kVp protocols with conventional spiral mode (Group B) were selected from the picture archiving and communication system. For each examination, the volume CT dose index (CTDIvol) and dose-length product (DLP), and the effective dose (adapted as 16-cm phantom) (ED_{16cm}) were estimated. The image noise, signal-to-noise ratio (SNR), overall subjective image quality and respiratory motion artefacts were evaluated.

Results: For radiation dose, CTDIvol (mGy), DLP (mGycm) and ED_{16cm} (mSv) of Group A were significantly lower than those of Group B [CTDIvol: $0.48 \pm$

0.003 mGy (Group A) vs 0.80 ± 0.005 mGy (Group B); $p < 0.001$ DLP: 10.23 ± 1.35 mGycm (Group A) vs 15.6 ± 2.02 mGycm (Group B); $p < 0.001$ ED_{16cm} : 0.61 ± 0.91 mSv (Group A) vs 0.89 ± 0.13 mSv (Group B); $p < 0.001$]. The mean image noise with Group A increased 28.5% ($p = 0.002$), and the mean SNR decreased 14.8% compared with Group B ($p = 0.193$). There was no statistical difference in overall subjective image quality grades, and Group A had significantly lower respiratory motion artefact grades than Group B ($p < 0.001$).

Conclusion: Ultralow tube voltage (70 kVp) combined with the Flash scan technique of the chest can obtain images with clinically acceptable image noise and minimum respiratory motion artefacts in low-weight children, whilst reducing radiation dose significantly.

Advances in knowledge: The feasibility of chest CT scan in low-weight children with ultralow tube voltage (70 kVp) combined with Flash scan technique has firstly been evaluated in our study.

INTRODUCTION

Multidetector CT is an important and increasingly used imaging technique in the paediatric population because it has contributed to a substantial increase in its diagnostic implications and accuracy in children.¹

The principal long-term disadvantage of CT is radiation exposure. Reducing radiation dose is especially important in children because organ radiosensitivity and the effective radiation dose from an individual CT examination are higher in children than in adults.^{2–5} It was reported⁶ that use of CT scans in children to deliver cumulative doses of about 50 mGy might almost triple the risk of leukaemia and doses of about 60 mGy might triple the risk of brain cancer. Therefore, it is necessary to reduce the medical radiation exposure to children as much as possible, the “as low as reasonably achievable” concept.

Although modification of tube current–time product was reported widely in reducing radiation dose in chest CT scans,^{1,7–13} lowering the tube voltage is the most direct and effective method of achieving radiation dose reduction.^{14–19} This setting for a tube voltage of 70 kVp could be accomplished due to the new generation of dual-source MDCT scanners.

Recently, the second generation dual-source CT (DSCT) system equipped with two 128-slice acquisition detectors has provided a high-pitch spiral mode which was named Flash scan. By combining this dual-source technology with the fastest available hardware components, including a gantry that rotates at 0.28 s, a patient table that can handle immense table feeds and ultrafast data transmission technology and an unprecedented scan speed of 458 mm s^{-1} can be achieved. Therefore, respiratory motion artefacts in

Table 1. Scan parameters for the two protocols

Protocol	Group A	Group B
Tube voltage (kVp)	70	80
Tube current (effect mAs)	50	50
Pitch	3.0	1.5
Detector collimation (mm)	2 × 64 × 0.6	32 × 1.2
Rotation time (s)	0.28	0.5
Slice thickness (mm)	3	3
Reconstruction algorithm	FBP	FBP
Flash spiral	Yes	No

FBP, filtered back projection algorithm.

children who are not able to hold a breath well could be reduced significantly.

The purpose of the present study was to evaluate the radiation dose and the image quality of a new scan protocol by using ultralow tube voltage (70 kVp) combined with Flash scan technique for chest CT scan in children.

MATERIALS AND METHODS

Study population

The prospective study complied with our local ethical guidelines was approved by the institutional ethics review board of the First People's Hospital of Wujiang. Informed written consent was obtained from every child's guardian.

During a 6-month period (June–November 2014) in our department, 30 consecutive children (weight <20 kg) underwent non-contrast enhanced chest CT at 70 kVp with Flash scan mode (classified as Group A). In order to perform comparative analysis of radiation dose and image quality, 30 (weight <20 kg) children scanned at 80 kVp on the same CT unit with conventional spiral scan mode (defined as standard protocol) during 2013 were selected from the picture archiving and communication system (PACS) workstation (classified as Group B). The main clinical indications for chest CT were acquired respiratory diseases for all cases.

CT scanning technique

The protocol parameters were different (Table 1). All studies were performed on a dual-source MDCT scanner (SOMATOM®-Definition Flash; Siemens, Forchhiem, Germany). All the patients were scanned always in the craniocaudal direction. All patients keep

Figure 1. A region of interest placed in the descending aorta at the level of the right pulmonary artery, mean attenuation and standard deviation (Std) in Hounsfield units were 76 and 20.9; signal-to-noise ratio was 3.63. Max, maximum; Min, minimum.

Table 2. Radiation dose for chest CT in paediatric patients for Groups A and B

Parameter	Group A (<i>n</i> = 30)	Group B (<i>n</i> = 30)	<i>p</i> -value
CTDIvol (mGy)	0.48 ± 0.003	0.80 ± 0.005	<0.001
DLP (mGy cm)	10.23 ± 1.35	15.60 ± 2.02	<0.001
ED _{16cm} (mSv)	0.61 ± 0.91	0.89 ± 0.13	<0.001

CTDIvol, volume CT dose index; DLP, dose-length product; ED_{16cm}, effective dose (adapted as 16-cm phantom).

Data are presented as mean ± standard deviation.

free breath during scan and no voice command for hold breath was applied. Contiguous transverse images were reconstructed with a slice thickness of 3 mm with a standard filtered back projection algorithm using a high-spatial-resolution kernel (B50, lung images) and a soft-tissue kernel (B20, mediastinal images), respectively.

Radiation dose

Radiation dose to the patient was acquired for each study by means of the two standard dose indicators—volume CT dose index (CTDIvol) and dose-length product (DLP)—calculated by the CT scanner and transferred to PACS automatically. The effective dose (ED) can be estimated as follows: $ED = DLP \times k$, using the DLP method with previously published age-dependent conversion factors *k* (newborn, 0.039; 1–4 years, 0.026; 5–9 years, 0.018; and 10–15 years, 0.013).²⁰ The *k*-values applicable for children were referenced to a 16-cm phantom for the CT systems used in this study, but CTDIvol was referenced to a 32-cm phantom for all body applications, including paediatric examinations, CTDIvol can be adapted as follows: $CTDIvol(16\text{ cm}) = d \times CTDIvol(32\text{ cm})$, coefficient *d* = 2.4 for DSCT.²¹

Image analysis

Image evaluation was performed on a clinical PACS workstation (NeuSoft Company; China). For each patient group, quantitative image noise and subjective image quality were evaluated. Image noise was determined by measuring the standard deviation (SD) in Hounsfield units and signal-to-noise ratio (SNR) was represented as the CT attenuation value/the SD. About a 1 cm² region of interest (ROI) was placed in the descending aorta at the level of the right pulmonary artery (Figure 1), using the method previously described by Jee-Eun Kim et al.¹⁴ When the area of the descending aorta was <1 cm², the size of the ROI was reduced appropriately. We measured the data twice, and the mean image noise and SNR were calculated for evaluation.

The overall subjective quality of the lung and the mediastinum image was assessed at the standard mediastinal window settings (width 400 HU, centre 40 HU) and lung parenchymal window settings (width, 1600 HU; centre, −600 HU). A 5-point scale was

used to grade image quality, and it was defined as: excellent (Grade 1), indicating there was clear depiction of anatomy without noise or artefacts; good (Grade 2), clear anatomy with mild noise or artefacts; satisfactory (Grade 3), adequate image quality for interpretation with mild to moderate noise or artefacts; poor (Grade 4), severe noise or artefacts with partial impairment of diagnostic accuracy; and non-diagnostic (Grade 5), severe noise and artefacts with marked impairment of diagnostic accuracy.^{14,17,18} A 4-point scale was used to grade image respiratory motion artefacts, and it was defined as: no respiratory motion artefacts (Grade 1); mild respiratory motion artefacts (≥ 1 slice and <3 slices) (Grade 2); moderate respiratory motion artefacts (≥ 3 slices and ≤ 5 slices) (Grade 3); serious respiratory motion artefacts (>5 slices) (Grade 4). Blinded to the protocol parameters, two thoracic radiologists with 5 years' experience interpreted the subjective image quality independently. In cases of discordant scores in subjective image analysis, the corresponding images were reanalyzed in the presence of a third reader with 10 years' experience and consensus agreement was achieved.

Statistical analysis

Differences between Group A and Group B in terms of demographic data, radiation dose and objective image quality were evaluated for statistical significance by using an independent-samples *t*-test. Non-parametric methods (Mann–Whitney *U* test) were applied to analyze image scores. Interobserver agreement on grades of image quality was assessed by kappa statistics ($\kappa > 0.81$, excellent; $\kappa = 0.61$ – 0.80 , good, $\kappa = 0.41$ – 0.60 , moderate; $\kappa = 0.21$ – 0.40 fair; $\kappa < 0.20$, slight agreement). SPSS v. 19.0 (IBM Corp., New York, NY; formerly SPSS Inc., Chicago, IL) was used for statistical analyses. Values were presented as means ± SD. A *p*-value <0.05 was considered statistically significant.

RESULTS

Study population

Group A patients included 20 males and 10 females (age: 2.9 ± 1.6 years; body weight: 13.4 ± 4.5 kg) and Group B patients

Table 3. Objective image quality for Group A and Group B examinations

Parameter	Group A (<i>n</i> = 30)	Group B (<i>n</i> = 30)	<i>p</i> -value
Noise (HU)	21.79 ± 5.97	16.95 ± 5.42	0.002
SNR	2.35 ± 1.12	2.76 ± 1.29	0.193

SNR, signal-to-noise ratio.

Data are presented as mean ± standard deviation.

included 18 males and 12 females (age: 3.0 ± 1.6 years; body weight: 13.7 ± 4.3 kg). There was no statistically significant difference in age and weight ($p > 0.05$) between the two groups.

Radiation dose

For Group A, the mean CTDIvol, DLP and ED_{16cm} were 0.48 mGy, 10.23 mGy cm and 0.61 mSv, respectively, and in Group B, these were 0.80 mGy, 15.6 mGy cm and 0.89 mSv, respectively. Compared with conventional scan protocol, the new protocol reduced CTDIvol by 40%, DLP by 34.4% and ED_{16cm} by 31.4% ($p < 0.001$) (Table 2).

Objective image quality

The mean image noise was significantly greater in Group A than in Group B (21.79 vs 16.95 HU, respectively; $p = 0.002$) and increased by 28.5%. The mean SNR in Group A was decreased by 14.8% than that in Group B (2.35 vs 2.76, $p = 0.193$). The objective image quality evaluation can be seen in Table 3.

Overall subjective image quality and respiratory motion artefacts

Figures 2 and 3 illustrate image quality in different scan protocols. In the two groups, no study was considered as Grade 5. There was no significant difference between the overall subjective image quality grades between the two groups ($Z = -0.157$, $p = 0.115$). For respiratory motion artefact grades, Group A had significantly lower grades than Group B ($Z = -5.271$, $p < 0.001$). No study was evaluated as Grades 3 and 4 in Group A; 3 cases were considered as Grade 4 in Group B, and the degrading of images in this group was caused by high respiratory rate caused by nerves. Figures 4 and 5 demonstrate the distribution of study cases based on overall subjective image quality grades and respiratory motion artefact grades, respectively.

The agreement on the subjective image scoring between the two observers was excellent ($\kappa = 0.89$), and there was good agreement for the respiratory motion artefacts scoring ($\kappa = 0.79$).

DISCUSSION

Radiation dose is proportional to the peak kilovoltage to the power of >2 , provided the tube current–exposure time product remains the same.²² Owing to the smaller size of the children, it is usually possible to lower the tube voltage with maintenance or even improvement of the diagnostic image quality, resulting in a significant dose reduction. In most children, a tube voltage of 80–100 kVp will suffice, especially in children with a body weight <45 kg. Several studies in recent years have reported using of 80-kVp^{21,23,24} and even 70-kVp¹⁹ protocols for scanning paediatric populations. The study by Niemann et al¹⁹ shows that at equivalent radiation dose levels, 70-kVp protocols provide similar image quality to that achievable at 80 kVp. Different from their study, our study population was limited to low-weight children. In our experience, when the tube voltage was set at 70 kVp in heavy-weight children, a relative increase in image noise and low SNR would cause confusion to the diagnosis sometimes, if other parameters were not adjusted. Meanwhile, we observed that in the study by Niemann et al, the subject scores for image quality in patients whose weight >15 kg were obviously lower than those in patients whose weight was <15 kg.

Figure 2. A 3-year-old male weighing 14 kg imaged with 70 kVp and Flash spiral technique. Images show ill-defined patchy exudation lesions in the inferior lobe of the left lung. Transverse CT images: mediastinal (a) and lung windows (b) that are rated as good image quality. (c) The coronal reconstruction image shows no respiratory motion artefacts, the edges of the ribs were sharp.

Figure 3. A 3-year-old female weighing 14 kg imaged with 80 kVp and conventional spiral scan. Images show patchy consolidation lesions in the inferior lobe of the bilateral lung. Transverse CT images: mediastinal (a) and lung windows (b) that are rated satisfactory image quality. (c) The coronal reconstruction image shows moderate respiratory motion artefacts, the edges of the rib were blurry.

Flash spiral scan technique is a new big pitch scan mode applied in the dual-source MDCT scanner (SOMATOM-Definition Flash). During scan, the two sets of independent X-ray tubes and the detector work at the same time, and the data is collected independently. Images can be obtained to the greatest degree of reduced respiratory motion artefacts. It has important meaning for children who cannot hold their breath well. The study by Lell et al²¹ shows that a high-pitch scan model can obtain excellent image quality in small children and infants at a very-low radiation doses compared with conventional pitch scan models although Z-overscanning increased to 6.6 cm for DSCT (pitch = 3.0).

To our knowledge, our study initially evaluated the radiation dose and image quality with ultralow tube voltage (70 kVp) combined with Flash scan technique. Our results showed that the radiation dose for the new protocol was reduced significantly compared with conventional protocols. The CTDIvol (0.48 mGy) obtained in Group A was quite low compared with other studies regarding low-radiation-dose chest scans in children which were published in the English literature.

Image noise is one of the most important factors determining image quality to make an accurate diagnosis.²⁵ Our study showed that the SNR between the two groups had no statistically significant difference although the mean image noise of Group A increased 28.5% compared with Group B. We considered reduction of tube voltage resulted in increased quantum mottle and background noise although patient body size was small in our study.

As we know, the subjective impression about image is very crucial in ordinary diagnostic work. For overall subjective grade, the new protocol can provide acceptable image quality equal to

Figure 4. The histogram shows the distribution of study cases based on overall subjective image quality grades.

Figure 5. The histogram shows the distribution of study cases based on respiratory motion artefact grades.

conventional scan protocols. For respiratory motion artefact grades, Group A has significant lower grades, and no patient was classified as Grades 3 and 4. It is noteworthy that the overall subjective and objective image qualities were discordant between the groups. Our interpretations are that firstly, the objective quality of the group with new protocol was inferior to that of the standard group because lower tube voltage lead to increase noise slightly. The difference was too

small to be distinguished by the estimator's subjective judgment. Respiratory motion artefacts were reduced to the lowest degree by Flash spiral scan with high temporal resolution. Therefore, the overall subjective quality score was more affected by respiratory motion artefacts than image noise and SNR in our study. Secondly, indication for chest scan in this study was acquired respiratory diseases. We consider that the display of lesions was affected more by respiratory motion artefacts than by noise.

Our study has some limitations. Firstly, it compared populations classified as two groups rather than individuals scanned twice with different protocols. Individual scanned twice at different protocols meanwhile was limited by ethics and the weight and characteristics of underlying diseases would change when acquired at a sequential examination. Secondly, in the study, the tube voltage and spiral scan mode were altered simultaneously between the two protocols, therefore if we want to study the detailed contribution for decreasing tube voltage and application of Flash scan mode to reducing radiation dose and influencing image quality, a more complex and rigorous research scheme is needed. Finally, in our study, all the images were obtained based on a standard filtered back projection algorithm. Furthermore, it is worthy to study whether a combination of iteration reconstruction with 70 kVp and Flash scan could acquire better image quality with a lower radiation dose.

In conclusion, ultralow tube voltage (70 kVp) combined with Flash scan technique can obtain images with clinically acceptable image noise and minimum respiratory motion artefacts compared with images scanned by conventional protocol with tube voltage (80 kVp) in low-weight children's chest scan and obviously reduce radiation dose.

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