Application of low dose radiation and low concentration contrast media in enhanced CT scans in children with congenital heart disease

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Summary
Objective: The aim of this study was to explore the feasibility of using low dose radiation and low concentration contrast media in enhanced CT examinations in children with congenital heart disease.

Materials and Methods: Ninety patients with congenital heart disease were randomly divided into three groups of 30 patients each who underwent contrast-enhanced cardiac scans on a Discovery CT750 HD scanner. Group A received 270 mg I/mL iodixanol, and group B received 320 mg I/mL iodixanol contrast media and was scanned with prospective ECG triggering mode. Group C received 320 mg I/mL iodixanol and was scanned with conventional retrospective ECG gating mode. The same weight-based contrast injection protocol was used for all three groups. Images were reconstructed using a 30% adaptive statistical iterative reconstruction (ASIR) algorithm and a 50% ASIR in groups A and B and a 30% ASIR in group C. The subjective and objective image quality evaluations, diagnostic accuracies, radiation doses and amounts of contrast media in the three groups were measured and compared.

Results: All images in the three groups met the diagnostic requirements, with the same diagnostic accuracy and image quality scores greater than 3 in a 4-point scoring system. However, ventricular enhancement and the objective noise, signal-to-noise ratio, contrast-to-noise ratio and subjective image quality scores in group C were better than those in groups A and B (all $P<.001$). The effective radiation dose in groups A and B was 84% lower than that in group C ($P<.001$); group A received the lowest contrast dose (14% lower than that of groups B and C).

Conclusion: Enhanced CT scan images with low dose radiation and low concentration contrast media can meet the diagnostic requirements for examining children with congenital heart disease while reducing the potential risk of radiation damage and contrast-induced nephropathy.

1 | INTRODUCTION

Congenital heart disease is caused by abnormal formation of the structures of the heart and great vessels during development of the embryo. Accurate diagnosis is essential for successful treatment. Transthoracic echocardiography (TTE), which is able to diagnose cardiac malformations and valvular disease, is non-invasive and simple but does not clearly visualise the malformations of the great vessels.
Cardioangiography (CAG) is the gold standard for the diagnosis of congenital heart disease. However, it is invasive, and the doses of radiation and contrast media are relatively large. Multi-slice spiral CT is non-invasive, has high temporal and spatial resolution and has great value and potential in the diagnosis of congenital heart disease in children. However, spiral CT carries with it the disadvantages of its radiation dose and contrast media-related adverse reactions; therefore, minimising these doses in children has attracted a great deal of attention. The aim of this study was to explore the application value of low dose radiation and low concentration contrast media in CT examinations of children with congenital heart disease.

2 | MATERIALS AND METHODS

2.1 | Clinical data

This study was approved by our institutional review board, and informed consent was obtained from the parents of all patients. Ninety patients with congenital heart disease who underwent enhanced CT scan in our hospital from November 2014 to June 2015 were enrolled in the study. These patients were randomly divided into three groups of 30 patients each: groups A and B were the experimental groups, while group C was the control group. All patients enrolled were younger than 4-year old; the groups were then randomised based on age, sex and body weight. Group A included 15 male and 15 female patients aged 1 month–4 years, with a median age of 7 months; group B included 16 male and 14 female patients aged 1 month–4 years, with a median age of 5 months; and group C included 15 male and 15 female patients aged 1 month–4 years, with a median age of 5.5 months.

2.2 | Examination method

All contrast-enhanced cardiac CT scans were performed on a Discovery CT750 HD scanner (GE Healthcare, Milwaukee, WI, USA). All patients were sedated with oral 10% chloral hydrate at a dose of 0.5 mL/kg body mass 30 minutes before the scan.

Patients in groups A and B were scanned using the prospective ECG triggering technique with a tube voltage of 80 kVp and the following age-based tube current settings with a gantry rotation speed of 0.35 seconds: 70 mA for newborns, 120 mA for 1 month–1 year old, 160 mA for 1–3 years old, 200 mA for 3–5 years old and 260 mA for 5 years and older. The scan start time and range were the same as in groups A and B. Images were also reconstructed at a slice thickness of 0.625 mm with an adaptive statistical iterative reconstruction (ASIR) algorithm of 30% strength.

The contrast medium was maintained at a constant temperature of 37 degrees before injection. Group A received 270 mg I/mL ioxaglate contrast, while groups B and C received 320 mg I/mL iodixanol contrast. Patient weight-dependent contrast volumes were used in all three groups: less than 3 kg: 2.0 mL/kg; 3–5 kg: 1.8 mL/kg; 5–10 kg: 1.6 mL/kg; 10–20 kg: 1.4 mL/kg; 20–50 kg: 1.2 mL/kg and more than 50 kg: 1.0 mL/kg. The maximum amount of contrast was 60 mL. A dual-head power injector was used. Contrast material was injected via peripheral veins in the elbow or the back of the hand. A standard contrast injection scheme was used: contrast medium with a flow rate 0.8–2 mL/s plus an 8–30 mL saline flush. Contrast medium was injected over 10–15 seconds. The delay time was set to 18–21 seconds.

2.3 | Image quality evaluation

Data were transferred to a GE advanced workstation (AW4.6) (GE Healthcare) to generate multi-planar reconstruction (MPR), maximal intensity projection (MIP) and volume rendering (VR) images for analysis.

2.3.1 | Objective image quality evaluation

The CT values in the back of a homogeneous muscle at the bottom of the heart and in the descending aorta (DA) were measured with a 15 mm² region of interest (ROI). The standard deviation (SD)
measurement in the same ROI of the homogeneous muscle was used to represent the objective image noise. The contrast-to-noise ratio (CNR) for the descending aorta was calculated as follows: CNR=[CT number (descending aorta) – CT number (back muscle)]/SD (back muscle). The signal-to-noise ratio (SNR) for the descending aorta was calculated as follows: SNR=[CT number (descending aorta)/SD (descending aorta)].

2.3.2 | Subjective score of image quality

Two senior doctors with more than 10 years of imaging experience reviewed the images using a blind method. The following 4-point scoring scheme was used for the subjective image quality evaluation based on image noise, artefact, structure and enhancement of the cardiac chambers and great vessels: 4=excellent image quality with limited perceptible image noise, no motion artefacts, well-defined heart chambers and great vessels with clear edges and excellent enhancement, fully acceptable for diagnosis; 3=good image quality with minor image noise and motion artefacts, well-defined heart chambers and great vessels with well-maintained walls and good enhancement, fully acceptable for diagnosis; 2=reduced image quality with moderate image noise and motion artefacts, limitations in the definition of the chambers and great vessel walls, acceptable for diagnosis under limited conditions; 1=impaired image quality limited by high image noise and motion artefacts, poor chamber and great vessel wall definition or poor lumen attenuation, unacceptable for diagnosis.

2.4 | Radiation dose

The volumetric CT dose index (CTDIvol) and dose length product (DLP) were recorded by the scanner. The size-specific dose estimate (SSDE) was calculated by multiplying the CTDIvol by size-specific conversion factors: SSDE=CTDIvol×f×(f). Conversion factor (f)=a×e−bx. x is effective diameter, a=3.70×10−2, b=3.67×10−2. The effective dose (ED) was calculated by multiplying the DLP by size-specific conversion factors and age-dependent conversion factors: ED=DLP×conversion factor (f)×conversion factor (c). The conversion factors (c in mSv/mGy-cm) were 0.039 for patients less than 1-year old; 0.026, for 1–5 years old; 0.018, for 6–10 years old and 0.013, for 11–18 years old.7

2.5 | Contrast media dosage

The total volume of contrast media and iodine content per kilogram of body weight were recorded.

2.6 | Statistical methods

All data were analysed using SPSS15.0 software. One-way ANOVA analysis was used for image quality assessments. In all analyses, P<.05 was defined as having statistical significance.

The correlation of the image quality scores between the two doctors was tested by the Kappa test. A Kappa value less than 0.20 was considered poor agreement; 0.21–0.40, fair agreement; 0.41–0.60, moderate agreement; 0.61–0.80, substantial agreement; 0.81–0.99, excellent agreement and 1, perfect agreement.

3 | RESULTS

3.1 | Patient characteristics

There was no significant difference in age, body weight and heart rate among the three groups (Table 1).

3.2 | Basic scan and recon parameters

Using the contrast agent with a lower iodine concentration, the iodine content per patient weight (mg I/kg) in group A was lower than that in groups B (P<.001) and C (P=.04). The contrast dose reduction was approximately 15%. There was no difference in iodine content per patient weight between groups B and C (Table 2).

The effective radiation dose in groups A and B was significantly lower than that in group C (P<.001), with an approximate 84% dose reduction. There was no difference in the effective radiation dose between groups A and B (P>.05).

3.3 | Objective evaluation of the image (Figs 1–3)

Objective noise values in groups A and B were significantly higher than that in group C (both P<.001). The SNR and CNR values in groups A and B were significantly lower than in group C (Table 3). There was no difference in the objective noise, SNR and CNR values between groups A and B (P>.05) when the same ASIR percentage was used. However, the use of a 50% ASIR in groups A and B helped improve the image noise, SNR and CNR values compared with the use of a 30% ASIR (all P<.001).

3.4 | Subjective image evaluation

Subjective image quality scores are listed in Table 4. The image quality scores in group C were significantly higher than those in groups A and B. However, based on the image quality scores, the images in all

### Table 1 Patient characteristics among the three patient groups

|                | Group A | Group B | Group C | P  |
|----------------|---------|---------|---------|----|
| Sex (male)     | 30 (15) | 30 (16) | 30 (15) | >.05 |
| Age, m²        | 7 (1–48) | 5 (1–48) | 5.5 (1–48) | >.05 |
| Weight, kg     | 8.07±3.37 | 7.57±3.88 | 7.20±3.03 | >.05 |
| Heart rate, bpm| 120.03±18.20 | 117.90±20.27 | 125.87±20.87 | >.05 |

Data are expressed as the mean±SD and median (range).
There was excellent agreement in the subjective image quality scores between the two observers, with a Kappa value of 0.81. Compared in the same group with a 30% ASIR and a 50% ASIR, the difference in the image quality scores was not statistically significant.

### Table 2: Imaging characteristics of the three patient groups

|                          | Group A          | Group B          | Group C          | P    |
|--------------------------|------------------|------------------|------------------|------|
| Contrast volume, mL      | 13.83±4.21       | 13.23±4.49       | 11.93±4.26       | >.05 |
| Iodine content, mg I/kg  | 4.82±0.59        | 5.63±0.81        | 5.57±1.90        | <.05 |
| CTDIvol, mGy            | 1.81±0.43        | 1.41±0.25        | 10.19±0.70       | <.001|
| SSDE                     | 3.84±0.85        | 3.27±0.58        | 23.62±3.07       | <.001|
| DLP, mGy-cm              | 19.89±7.38       | 15.22±4.96       | 102.32±22.68     | <.001|
| ED, mSv                  | 1.27±0.34        | 1.25±0.33        | 8.13±2.54        | <.001|
| Scan length, mm          | 107.33±20.42     | 106.17±21.52     | 100.35±21.05     | >.05 |
| Tube potential, kVp      | 80               | 80               | 80               |      |
| Reconstruction algorithm | ASIR             | ASIR             | ASIR             |      |
| Reference tube current, mA| newborn=70;      | newborn=70;      | newborn=200;     |      |
|                          | 1 month–1 year=120; | 1 month–1 year=120; | 1 month–5 years=260; |      |
|                          | 1–3 years=160;   | 1–3 years=160;   | >5 years=300.    |      |
|                          | 3–5 years=200;   | 3–5 years=200;   |                  |      |
|                          | >5 years=260.    |                  |                  |      |

Data are expressed as the mean±SD.

### Figure 1

Group A, male, 2 months. (a) 30% ASIR, descending aorta: 368.61±28.01 Hu, back muscle: 76.75±21.99 Hu. (b) 50% ASIR, descending aorta: 367.43±26.61 Hu, back muscle: 76.66±20.80 Hu

### Figure 2

Group B, male, 5 months. (a) 30% ASIR, descending aorta: 463.44±25.65 Hu, back muscle: 63.33±18.79 Hu. (b) 50% ASIR, descending aorta: 462.22±24.14 Hu, back muscle: 63.32±17.43 Hu

### 3.5 Diagnosis accuracy for congenital heart abnormalities

The congenital heart abnormalities of the great vessels in the three groups are listed in Table 5. The diagnostic accordance rates of the
extracardiac anomalies of the three groups were 100%. The diagnostic accordance rates of the intracardiac anomalies were 100% for groups A and C and 96% for group B. Two cases of valvular anomalies could not be clearly displayed in group B. Different strengths of the adaptive statistical iterative reconstruction (ASIR) algorithm had no effect on diagnostic accuracy.

4 | DISCUSSION

The sensitivity of children to radiation is significantly higher than that of adults; the younger the age, the greater the risk of radiation. Therefore, “as low as reasonably achievable (ALARA)” is very important in children requiring CT scanning. In addition, contrast media induced nephropathy (CIN) is one of the main risk factors for iatrogenic renal failure. CIN has a direct correlation with the dosage and concentration of contrast media. Reducing the dosage of contrast media in an effort to reduce the incidence of CIN is also very important in enhanced CT examinations for paediatric patients.

In this study, the following techniques were used to reduce the radiation dose: prospective ECG-triggered scanning, adaptive statistical iterative reconstruction and low tube voltage and tube current. The prospective ECG-gated scanning technique is a very effective method of reducing the radiation dose in cardiac CT examination; the radiation dose can be reduced by 70%–90% but has stricter requirements for heart rate and cardiac rhythm. Faster heart rates, more heart rate variability or arrhythmia scan result in loss of image quality and possibly misdiagnosis. Infants and younger children have faster heart rates and more heart rate variability. If associated with congenital heart disease, these are more frequently accompanied by arrhythmia, making it difficult to meet the basic requirements of prospective ECG-triggered scanning; therefore, retrospective ECG gating is more often used for pediatric patients. Modern CT scanner have improved temporal resolution and more robust optimal cardiac phase selection for better coronary CT angiography image quality. In this study, we set a padding time (PT) before and after a preset cardiac phase to improve image quality and the success rate. The PT was set to 80 milliseconds based on heart rate, 45% for the scheduled phase, and the data from the 35% to 55% phases could also be reconstructed.

Iterative reconstruction techniques, such as the adaptive statistical iterative reconstruction (ASIR) algorithm, can significantly reduce the image noise in low dose scanning, while the use of iterative reconstruction techniques can play an indirect role in further reducing the radiation dose.

The combined use of prospective ECG-triggered scanning, adaptive statistical iterative reconstruction, low tube voltage and low tube current provides a solution for a further reduction in radiation dose. In this study, the radiation dose of the experimental group was significantly lower than that of the control group, with the radiation dose

### TABLE 3 Objective image quality comparison

| Group       | 30% ASIR          | 50% ASIR          | 30% ASIR          | 50% ASIR          | 30% ASIR          | P       |
|-------------|-------------------|-------------------|-------------------|-------------------|-------------------|---------|
| CT number   | 404.5±81.97       | 404.0±81.56       | 503.4±95.84       | 503.3±95.62       | 500.19±91.18     | <.001   |
| SDa         | 23.51±3.92        | 21.86±3.64        | 24.67±2.81        | 22.95±2.61        | 19.51±3.36       | <.001   |
| SNR         | 16.16±4.33        | 17.19±4.61        | 19.36±3.57        | 20.60±3.80        | 25.01±6.84       | <.001   |
| CNR         | 14.77±4.18        | 15.89±4.49        | 17.78±4.27        | 19.12±4.59        | 22.94±6.14       | <.001   |

*SD refers to the objective image noise. Data are expressed as the mean±SD. CT number refers to the CT attenuation values in the descending aorta. SNR, signal-to-noise ratio; CNR, contrast-to-noise ratio.

### TABLE 4 Subjective image quality

| Group       | A       | B       | A       | B       | A       | B       | P       |
|-------------|---------|---------|---------|---------|---------|---------|---------|
| Group A     |         |         |         |         |         |         |         |
| 30% ASIR    | 3.06±0.12| 3.03±0.14| 3.08±0.12| 3.08±0.15| 3.35±0.15| 3.37±0.15| <.001   |
| 50% ASIR    | 3.05±0.10| 3.06±0.13| 3.09±0.12| 3.07±0.14|         |         | >.05    |

Data are expressed as the mean±SD. Possible image quality scores ranged from 1 to 4.
decreased by approximately 84%. Although the lower radiation dose scans caused a certain amount of image quality degradation in terms of image noise, all images in the low dose scan groups met the clinical diagnostic requirements; the use of higher percentage ASIR further reduced image noise.

Recent studies have demonstrated that the incidence of CIN was 7% after enhanced CT. The updated European Society of Urogenital Radiology contrast media safety committee guidelines stressed the importance of using a minimal dose of low-osmolar or iso-osmolar contrast medium for diagnostic examinations. Administration of a low iodine concentration contrast medium has the potential to decrease nephrotoxicity.

The 270 mg I/mL iodixanol is an iso-osmotic contrast medium with a low iodine concentration and low viscosity. In this study, group A received a low concentration of 270 mg I/mL iodixanol contrast, which reduced the mg I/kg contrast dose by 13%–15% compared with the 320 mg I/mL iodixanol group. The CT values of the enhanced atrium, ventricle and great vessels were reduced due to the use of low concentrations of contrast media. Using 80 kVp of tube voltage compensated for the enhancement reduction due to the reduced contrast concentration and improved the contrast between the blood vessels and soft tissue. The enhancement degrees in the cardiac ventricles and great vessels were correlated with not only the total amount and concentration of the contrast media but also with the injection flow rate of the contrast. Previous studies have shown that 300 mg I/mL contrast media is superior to 370 mg I/mL contrast media in the great vessels. This is because the lower viscosity contrast medium can achieve a higher injection flow rate to meet the requirements for the enhancement of the great vessels. The use of an appropriate low tube voltage and contrast media injection flow rate can reduce the impact of the diminished contrast between the blood vessels and soft tissues caused by the use of low concentration contrast media. In this study, the degrees of ventricular enhancement in all three groups were satisfactory for clinical diagnosis.

In this study, the objective image noise, signal-to-noise ratio and subjective image score for the control group were better than those in the experimental groups. However, the use of iterative reconstruction effectively suppressed the image noise in all three groups to ensure adequate image quality. The images in the experimental groups and control group were sufficient for diagnostic requirements. There was no significant difference in the diagnostic accuracies of the three groups.

This study had a limitation in that the sample size was small. Further studies with larger patient populations are warranted to confirm these findings.

In summary, enhanced CT scan images using low dose radiation and low concentration contrast media can meet the diagnostic requirements for examining children with congenital heart disease and reduce the potential risk of radiation damage and contrast-induced nephropathy.
DISCLOSURES

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