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Comparison of Image Quality, Diagnostic Accuracy and Radiation Dose Between Flash Model and Retrospective ECG-Triggered Protocols in Dual Source Computed Tomography (DSCT) in Congenital Heart Diseases

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Summary

Background:

Dual source computed tomography (DSCT) plays an important role in the diagnosis of congenital heart diseases (CHD). However, the issue of radiation-related side effects constitutes a wide public concern. The aim of the study was to explore the differences in diagnostic accuracy, radiation dose and image quality between a prospectively ECG – triggered high – pitch spiral acquisition (flash model) and a retrospective ECG-gated protocol of DSCT used for the detection of CHD.

Material/Methods:

The study included 58 patients with CHD who underwent a DSCT examination, including two groups of 29 patients in each protocol. Then, both subjective and objective image quality, diagnostic accuracy and radiation dose were compared between the two protocols.

Results:

The image quality and the total as well as partial diagnostic accuracy did not differ significantly between the protocols. The radiation dose in the flash model was obviously lower than that in the retrospective model ($P < 0.05$).

Conclusions:

Compared to the retrospective protocol, the flash model can significantly reduce the dose of radiation, while maintaining both diagnostic accuracy and image quality.

MeSH Keywords:

Image Enhancement • Jervell-Lange Nielsen Syndrome • Multidetector Computed Tomography • Radiation Dosage

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Background

CT has seen a rapid technical improvement in recent years, with improved temporal and spatial resolutions and better image post-processing. Moreover, CT is a noninvasive procedure. All these advantages have made CT a useful modality for the detection of congenital heart diseases (CHD), especially in the case of complex CHD. While CT imaging of CHD has become more popular, concerns have been raised about the overuse of ionizing radiation in vulnerable patients, especially in infants and young children. How to obtain a satisfying CT image quality with an ultra-low radiation dose in infants and young children with CHD

remains challenging [1]. A second generation dual source CT system has the advantage of providing a high-pitch spiral mode, which makes it possible to acquire the entire data within a single cardiac cycle. Some studies [2] have shown ultra-low radiation doses of less than 0.1 mSv. The aim of the study was to explore the differences in diagnostic accuracy, radiation dose and image quality between a prospectively ECG-triggered high – pitch spiral acquisition (flash model) and a retrospective ECG-triggered model in dual source computed tomography (DSCT) for the detection of congenital heart diseases.

Table 1. Comparison of radiation dose.

	Flash	Retrospective	t	P
CTDIvol	1.14±0.49	9.85±3.73	-12.425	0.000
DLP	23.51±13.81	204.72±103.83	-9.316	0.000
ED	0.45±0.23	3.66±1.92	-8.921	0.000

CTDIvol – CT dose index volume; DLP – dose length product; ED – effective dose.

Material and Methods

Patients

From January 2015 to February 2016, we included 58 patients with CHD who underwent a DSCT examination. The patients were divided into two groups - 29 patients in the flash group (mean age: 5.89 years; range: 5 months–35 years; male: 19; female: 10) and 29 patients in the retrospective protocol group (mean age: 4.96 years; range: 4 months–21 years; male: 16; female: 13). In total, 40 patients underwent surgical treatment. Written consent was obtained from the patients or their parents.

DSCT protocol

All patients underwent flash CT (Siemens Definition). We protected vital organs of patients before scanning. The patients were trained to comply with breathing restrictions, and infants were examined under general anesthesia or chloral hydrate 50–100 mg/Kg. ECG-gated modulation, pitch automatic matching technology and Sinogram Affirmed Iterative Reconstruction (SAFIRE) were used. The scan range was from the thoracic inlet to the bottom of the diaphragm. The parameters of flash were – high-pitch of 3.4; starting at 55% of the R–R interval; acquisition collimation: 128×0.6 mm; slice thickness: 0.6 mm; gantry rotation time: 0.28 second; tube voltage: 80 Kv; Care Dose 4D technology was used, the reference tube current was 110 mAs. The parameters of the retrospective ECG-gated protocol were – pitch: 0.17; starting at BestDiast; the other parameters were similar to flash. Contrast medium used was Visipaque (270 mg/mL; GE Healthcare), flow rate: 0.17 mL/Kg/s with bolus tracking, the region of interest was double the ventricle level when the density value of left ventricle reached 100 HU. The scan commenced automatically after a delay of 2 seconds.

Diagnostic analysis

Two experienced radiologists analyzed the data. The post-processing techniques of volume rendering (VR), maximum intensity projection (MIP) and multiplanar reformation (MPR) were used. Surgery findings were treated as the gold standard. Cardiovascular anomalies were divided into intra-cardiac anomalies, large vascular connecting anomalies of the heart and extra-cardiac anomalies according to the anatomical structure. We calculated the diagnostic accuracy.

Radiation dose

Dose length product (DLP) and CT dose index volume (CTDIvol) of the two groups were recorded. Effective dose

(ED) was estimated according to an equation ($ED = DLP \times k$) where k is the conversion coefficient [1,3] varying according to age (infants up to 4 months, $k = (0.039 \text{ m Sv} \cdot \text{mGy}^{-1} \cdot \text{cm}^{-1})$, from 4 months to 1 year of age, $k = 0.026 \text{ m Sv} \cdot \text{mGy}^{-1} \cdot \text{cm}^{-1}$, from 1 year to 6 years of age, $k = 0.018 \text{ m Sv} \cdot \text{mGy}^{-1} \cdot \text{cm}^{-1}$ and older than 6 years old, $k = 0.014 \text{ m Sv} \cdot \text{mGy}^{-1} \cdot \text{cm}^{-1}$).

Image quality analysis

The subjective image quality was estimated according to a five-point scale [4], where "5" was excellent; "4" was good; "3" was applicable; "2" was poor; "1" was unable to diagnose. Scores 3-5 were satisfying.

The objective image quality was estimated based on CT values, image noise, signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR). CT values and image noise were measured on the ascending aorta, main pulmonary artery, left ventricular cavity and dorsal muscles. ROI were drawn as large as possible. Then, we calculated SNR and CNR according to an equation ($SNR = CT / \text{image noise}$, $CNR = (CT - CT_{\text{muscle}}) / \text{image noise}$) [5].

Statistical analysis

The 17.0 SPSS software was used for statistical analysis. The Mann-Whitney U test was used to compare subjective image quality. Objective parameters and radiation dose were compared by the T test. Diagnostic accuracy was compared by the chi-square test. A P value lower than 0.05 was considered statistically significant.

Results

There was no statistical difference in both age and weight between the two groups. All patients successfully completed the examinations.

Radiation dose in two groups

The radiation dose measured by flash was obviously lower than that in the retrospective protocol, and there was a statistically significant difference. The effective radiation dose was reduced by 87.7% (Table 1).

Image quality in two groups

All images were of a satisfying quality. Some examples are shown in Figures 1–3.

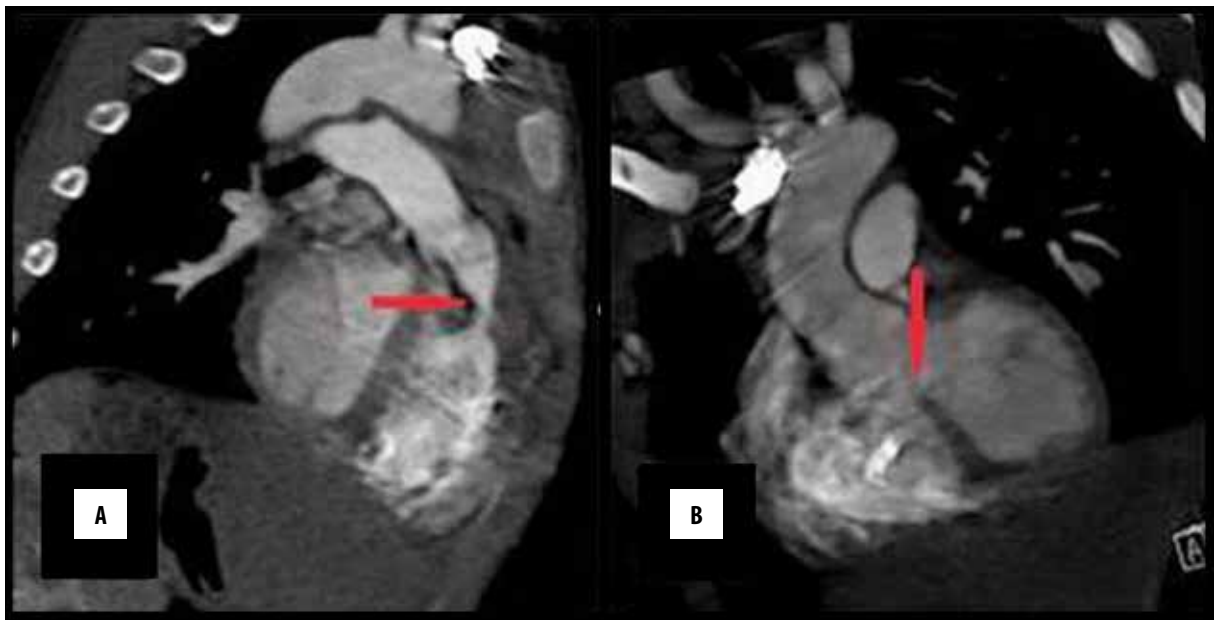


Figure 1. Multiplanar reformation sagittal (A) and coronal (B) images of a 4-year-old girl with an overriding aorta (arrow B) and right ventricular outflow tract stenosis (arrow A), obtained with the use of the retrospective ECG-gated protocol.

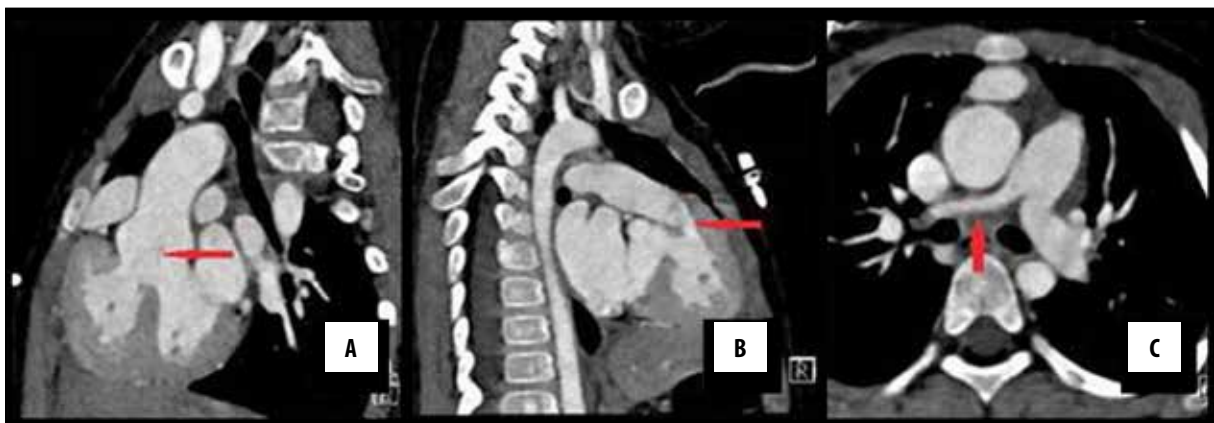


Figure 2. Multiplanar reformation coronal (A), sagittal (B) and axial (C) images of a 4-year-old boy with an overriding aorta (arrow A) and right ventricular outflow tract stenosis (arrows B, C), obtained with the use of the flash model.

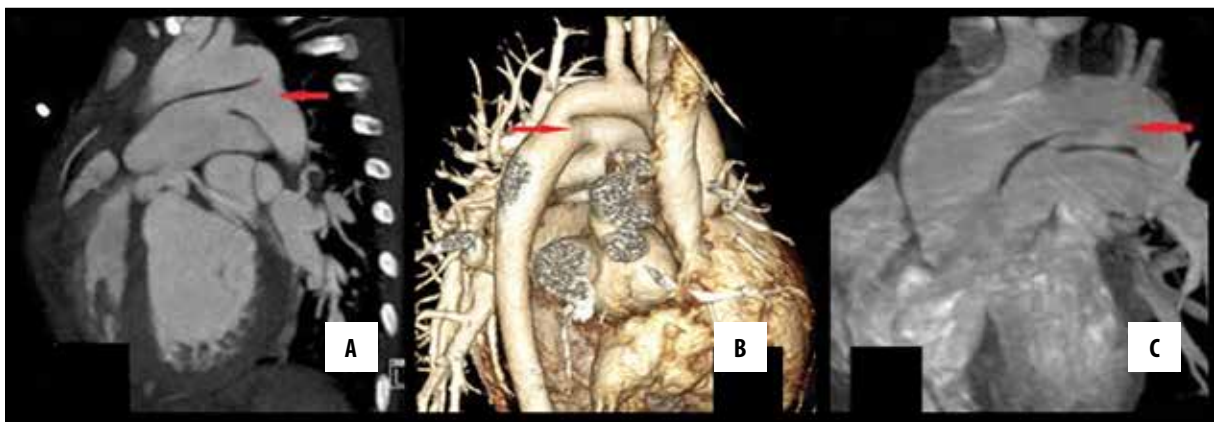


Figure 3. Multiplanar reformation sagittal (A) and volume rendering (B) images of a 3-year-old girl with a patent ductus arteriosus (arrows A, B) obtained with the use of the retrospective ECG-gated protocol. Maximum intensity projection (C) images of a 3-year-old boy with a patent ductus arteriosus (arrow C) obtained with the use of the flash model.

Table 2. Comparison of objective image quality.

		Flash	Retrospective	t/Z	P
CT value	AA	473.37±177.48	467.27±132.29	0.173	0.863
	MPA	424.75±158.64	421.03±138.58	0.095	0.924
	LV	460.10±173.52	451.82±119.55	0.211	0.833
	Muscle	70.82±23.63	77.48±16.54	-1.242	0.219
Image noise	AA	29.31±12.17	24.27±6.05	1.994	0.053
	MPA	29.17±10.39	25.13±9.34	1.554	0.126
	LV	33.10±13.38	28.65±6.23	1.622	0.113
	Muscle	27.10±10.86	22.55±10.26	1.640	0.107
SNR	AA	18.11±8.54	20.16±6.44	-1.034	0.305
	MPA	15.63±6.40	17.60±5.31	-1.276	0.207
	LV	16.12±07.74	19.63±6.45	-1.873	0.066
	Muscle	3.13±1.68	3.94±1.58	-1.900	0.063
CNR	AA	15.33±7.95	16.36±5.59	-5.700	0.571
	MPA	13.00±6.18	14.18±5.18	-7.890	0.433
	LV	13.65±7.12	13.43±4.79	0.135	0.893

SNR – signal-to-noise ratio; CNR – contrast-to-noise ratio.

The subjective image quality was evaluated in the range of 3–5 points, the mean score was 3.72(±0.80) in the flash group and 4.00(±0.75) in the retrospective group, with no significant difference ($Z=-1.221$, $P=0.222$).

There were no statistically significant differences in any of the objective parameters between the two groups (Table 2).

Diagnostic accuracy in two groups

The overall diagnostic accuracy of the flash and retrospective models was 87.1(81/93) and 86.7% (65/75), respectively, with no statistically significant difference ($\chi^2=0.007$, $P=0.935$), (Table 3).

With respect to the intra-cardiac anomalies, the diagnostic accuracy of the flash and retrospective models was 82.9% (29/35) and 83.3% (25/30), respectively, with no statistically significant difference ($\chi^2=0.030$, $P=0.959$). With respect to the large vascular connecting anomalies of the heart, the diagnostic accuracy was 91.3% (21/23) and 84.2% (16/19), respectively, with no statistically significant difference between the two groups ($\chi^2=0.052$, $P=0.820$). With respect to the extra-cardiac anomalies, it was 88.6%(31/35) and 92.3% (24/26), respectively, with no statistically significant difference ($\chi^2=0.002$, $P=0.960$).

Discussion

Congenital heart disease is common in infants and young children, and most congenital heart diseases can be cured or relieved by surgical correction. An accurate and detailed preoperative evaluation plays an important role in planning surgery, which is key to a successful repair of CHD [6].

A good image quality guarantees accurate diagnosis. Our study showed that the two scanning modes of DSCT can obtain satisfying image quality. The image quality in the retrospective group was better than that in the flash group, however, there was no statistically significant difference. In the flash model, regular heart rate is key to obtaining a satisfactory image quality, because the data are acquired within a certain time frame of a single cardiac cycle. The advantage of the retrospective ECG-gated protocol with dual-source CT is that it is not limited by heart rate, which is suitable for patients with a high heart rate [7]. In addition, the retrospective model can analyze cardiac function.

Our study showed that the two scanning modes of DSCT have a high diagnostic accuracy in detecting cardiovascular anomalies. Both the total and partial diagnostic accuracy was comparable between the models. The volume data obtained from CT can better show subtle structures through powerful post-processing techniques. CT has an absolute advantage for diagnosing extra-cardiac anomalies [8,9], coronary artery anomalies [6,10] and assessing the development of pulmonary artery before surgery [11].

Studies have shown that children with CHD receive too much cumulative doses that can cause DNA damage [12]. Therefore, reducing radiation dose is currently the most important issue for infants and young children. It reminds radiologists that before each examination the principle of "as low as reasonably achievable" (ALARA) should be applied. The dose reduction strategies must be well and properly used, and include reduced tube voltage, high-pitch scans, prospective ECG-gated modes and technologies of automated tube current modulation [13,14]. Our study employed the above method as we aimed to reduce

Table 3. Comparison of diagnostic accuracy.

Cardiovascular deformities	Flash			Retrospective		
	Surgery	Detect	Fault	Surgery	Detect	Fault
Intra-cardiac anomalies						
Atrial septal defect	4	3	1	3	3	
Right ventricular hypertrophy	10	9	1	10	9	1
Ventricular septal defect	16	15	1	12	12	
Discrete subaortic membrane				1		1
Patent foramen ovale	5	2	3	4	1	3
Heart-large vascular connecting anomalies						
Overriding aorta	10	10		10	9	1
Pulmonary arterial hypertension	3	2	1	3	3	
Right ventricular outflow tract stenosis	4	4		4	3	1
Right ventricular outflow tract broadening	1	1				
Transposition of great arteries	2	2		1		1
Double outlet right ventricle	3	2	1	1	1	
Extra-cardiac anomalies						
Pulmonary artery stenosis	17	14	3	11	9	2
Coarctation of the aorta	1	1		3	3	
patent ductus arteriosus	9	8	1	3	3	
Coronary artery anomaly	1	1		2	2	
Collateral abnormal	3	3		4	4	
Persistent left superior vena cava	2	2		1	1	
Aortopulmonary window	1	1				
Pulmonary artery atresia				1	1	
Anomalous pulmonary venous return				1	1	
Cor triatriatum	1	1				
Total	93	81	12	75	65	10

the radiation dose and we also protected the vital organs of patients before scans. Moreover, we used the Care Dose 4D technology, ECG-gated modulation, pitch automatic matching technology and SAFIRE. Several studies have shown the advantage of SAFIRE in image noise reduction and improved image quality [15–17], which has been used for cardiac CT and have effectively reduced the radiation dose. Our study showed that the radiation dose measured by the flash mode was lower than that in the retrospective protocol ($P < 0.05$), and the effective dose was reduced by 87.7%. Schuhbaeck et al. [2] reported an average radiation dose of less than 0.1 mSv. This is attributed to a high-pitch spiral.

The reason why our study showed a slightly higher radiation dose is that we included adults. How to obtain a satisfying diagnostic CT image quality with ultra-low radiation doses in infants and young children with CHD still remains challenging.

Conclusions

In conclusion, the two models can achieve a satisfying image quality and have a high diagnostic accuracy. The flash model can significantly help reduce the radiation dose as compared to the retrospective ECG-triggered protocol.

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