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ORIGINAL ARTICLE

Evaluation of coronary artery variations using dual-source coronary computed tomography angiography in neonates with transposition of the great arteries

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Abstract

Objective The purpose of this study was to investigate whether the origins and courses of the coronary arteries could be better assessed using ECG-gated dual-source computed tomography (CT) than with echocardiography in neonates with transposition of the great arteries (TGA).

Methods A total of 17 neonates within 14 days old who underwent both echocardiography and retrospective ECG-gated coronary CT angiography were retrospectively reviewed. The patients were sedated and intubated during CT examinations, and CT images were obtained with a breath-hold. CT images were reconstructed by multiple cardiac phases, and the coronary artery assessment was performed in the most static phase. Coronary anomalies were classified by Shaher's classification and validated by surgical findings.

Results CT correctly classified 16 of 17 cases (Shaher type 1: 7, type 2: 4, type 9: 3, type 3: 1, type 4: 2), whereas echocardiography classified only 8 of 17 cases correctly. Dual-source CT had a significantly higher diagnostic ability than echocardiography ($p = 0.0078$).

Conclusion Dual-source coronary CT angiography has a higher diagnostic ability than echocardiography in the assessment of the origins and courses of the coronary arteries in neonates with TGA.

Keywords Transposition of the great arteries · Coronary anomalies · Cardiac CT · Neonate

Abbreviations

ECG	Electrocardiogram
TGA	Transposition of the great arteries
CHD	Congenital heart disease
ASO	Arterial switch operation
MDCT	Multi-detector row computed tomography
VR	Volume rendering
MPR	Multiplanar reformation
$CTDI_{vol}$	Volume CT dose index
DLP	Dose-length product
SD	Standard deviation
TTE	Transthoracic echocardiography
LCX	Left circumflex artery
RCA	Right coronary artery
LAD	Left anterior descending artery

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Introduction

Congenital heart disease (CHD) is one of the common congenital defects, affecting an estimated 6 in 1000 live births [1]. Transposition of the great arteries (TGA) accounts for 5% to 7% of all CHDs [2–4], with a prevalence of 0.2 per 1000 live births [5]. TGA is one of the most frequent cyanotic CHDs [6] diagnosed in the neonatal period [2].

Most patients with TGA must undergo the arterial switch operation (ASO) in the neonatal period. Coronary artery transfer and implantation are the most critical steps in the ASO. There is a technical difficulty in translocating coronary arteries in some coronary artery anomalies, such as single, intramural, double orifice originating from the same sinus of Valsalva, and inverted coronary arteries, which is associated with increased surgical morbidity and mortality [7–9]. Therefore, the preoperative identification of coronary anatomy in neonates with TGA is clinically important for surgical planning.

Transthoracic echocardiography and cardiac catheterization have been the main modalities for evaluating coronary artery anatomy in neonates with TGA. However, accurate identification of coronary anatomy using echocardiography is not easy when complex coronary artery variations exist. Further, the technique of the operator has a large effect on diagnostic ability in echocardiography.

Technical advancements in CT have allowed high temporal and spatial resolution and have led to increased use of CT for the evaluation of CHD in children. We hypothesized that the high temporal resolution of dual-source CT might enable the visualization of coronary arteries in neonates with a small body and a high heart rate. Several studies have reported the image quality of coronary arteries on coronary CT angiography in children with congenital heart disease [10–13]. However, with regard to neonates with TGA, the feasibility of dual-source CT angiography for identifying coronary anatomy has not been investigated. The purpose of this study was to assess the ability of dual-source CT angiography to evaluate coronary anatomy in neonates with TGA and compare it with that of echocardiography.

Materials and methods

Patients

A total of 17 neonates (15 boys and 2 girls; mean age 5.2 ± 3.0 days, range 1–13 days; mean weight 2916 ± 425 g, range 2110–4019 g) who underwent coronary CT angiography and echocardiography within the first 14 days after birth between December 2015 and February 2017 were retrospectively reviewed.

CT techniques

All examinations were performed with a dual-source 128-MDCT scanner (Somatom Definition Flash, Siemens Healthcare, Forchheim, Germany) with a gantry rotation time of 280 ms. Intravenous sedative (midazolam or thiamylal sodium) was administered according to each patient's weight. All patients except one were intubated (9 were already intubated and were on artificial ventilation because of their clinical conditions, 7 were intubated for CT preparation), and CT examinations were conducted under breath-hold by an attendant doctor. The non-ionic contrast agent iopamidol (370 mg I/mL) at a volume of 2 mL/kg was mixed with physiological saline solution in a 1:1 ratio and injected through a 24-gauge catheter with a dual-syringe injector in 20 s. The scan was started at a fixed time, 22 s after the start of injection. Two patients were given a short-acting selective beta-1 blocker (landiolol hydrochloride) for heart rate control, and six were given muscle relaxant (vecuronium bromide) to completely suppress body movement.

CT parameters were as follows: automated tube voltage (Care KV, Siemens Healthcare); scout-based automatic reference tube current selection (CareDose 4D, Siemens Healthcare); gantry rotation time, 0.28 s; detector array, 2 × 128 × 0.6 mm using a z-flying focal spot technique; pitch, 0.17; and temporal resolution, 75 ms.

Data from all cardiac phases of the R–R interval were obtained with retrospective ECG-gated scanning. Data were reconstructed with an iterative reconstruction algorithm (sonogram-affirmed iterative reconstruction, SAFIRE; Siemens Healthcare).

A normal soft tissue reconstruction kernel (I36, I26, and/or I41) was used with a section thickness of 1.0 mm and reconstruction intervals of 0.5 or 0.6 mm.

Image processing

All images were transferred to a postprocessing workstation (Synapse Vincent; Fujifilm Medical Systems, Tokyo, Japan). Multiphase reconstruction at intervals of 5% of the cardiac phase was performed, which allowed coronary anatomy interpretation at the best motion-free cardiac phase. Volume rendering (VR) and/or multiplanar reformation (MPR) was used in addition to axial images to evaluate coronary artery anatomy.

Coronary artery anatomy analysis

Shaher's classification was used to describe coronary anatomy (Fig. 1) [14].

Two radiologists (YO and NK with 5 and over 30 years clinical experience, respectively) who were blinded to

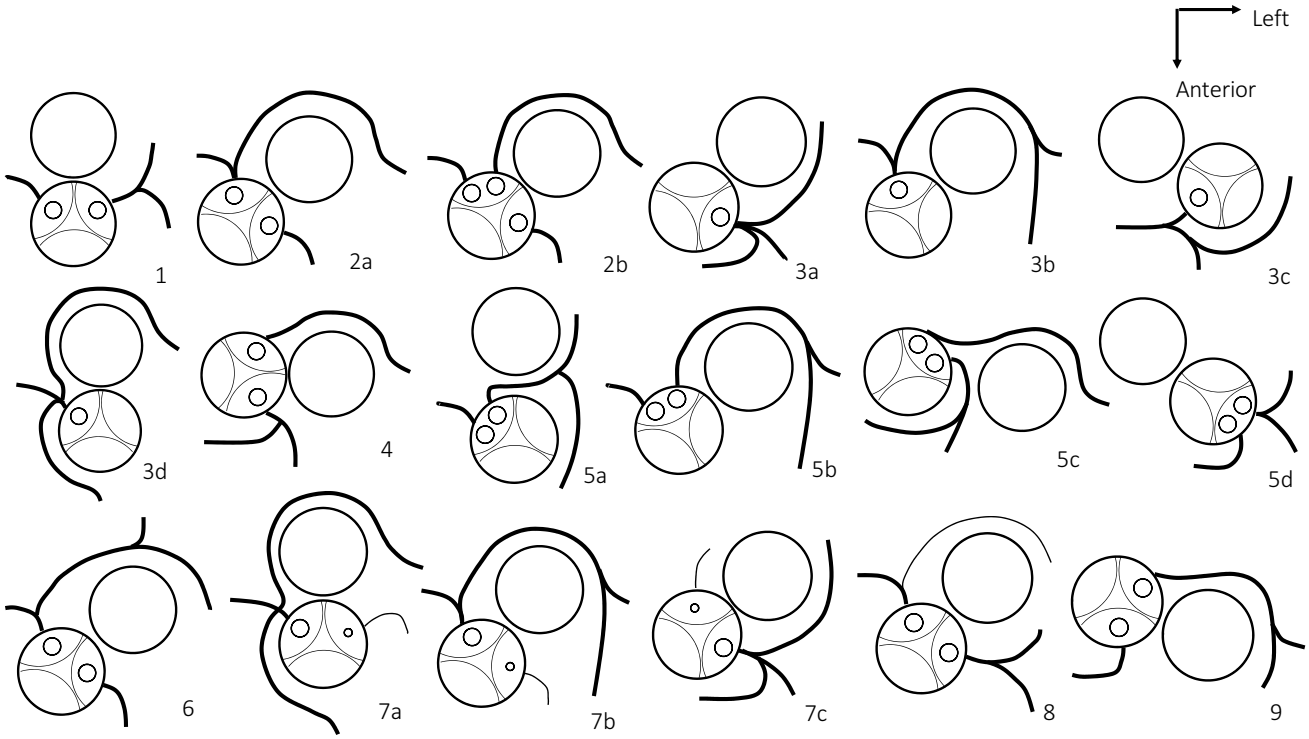

Fig. 1 Shaher's classification

patients' echocardiography or coronary angiography findings determined the coronary anatomy classification using images at one or more well-visualized cardiac phases. There was no disagreement in the interpretation between the two observers. The coronary classification determined by CT was then compared with the classification confirmed by surgery, and diagnostic accuracy was calculated. Transthoracic echocardiography examination (CX50, Philips and/or EPIC 7, Philips, Amsterdam, The Netherlands) was performed by one or two pediatric cardiologists with over 6–8 years clinical experience in congenital cardiology. The coronary classification by echocardiography was also compared with surgical results in the same way.

Radiation dose calculation

The volume CT dose index ($CTDI_{vol}$) and dose-length product (DLP) were recorded for each CT examination. The $CTDI_{vol}$ and DLP were obtained for a 32-cm phantom. The DLP based on the 32-cm phantom was multiplied by a scanner-specific factor of 2.4 (for 70 kV) or 2.3 (for 80 kV) provided by the scanner manufacturer to obtain the radiation doses based on a 16-cm phantom. This value was then multiplied by the age-specific conversion factor for the chest (0.039 mSv/mGy cm for children younger than 4 months old) to calculate the effective dose (mSv) [15]. Also, $CTDI_{vol}$ was converted into size-specific dose estimates (SSDE) by the conversion factor based on the sum of the anteroposterior dimensions and lateral dimension [16]. One patient's data on radiation dose was lost, so 16 patients' data were included.

Statistical analysis

Data are presented as means and standard deviations. The Wilcoxon rank-sum test was used to compare the diagnostic accuracies of dual-source CT and echocardiography. Only p values less than 0.05 were considered significant. GraphPad Prism version 6.0 (GraphPad Software, Inc., San Diego, CA, USA) was used for statistical analysis.

Results

The 17 patients' demographic characteristics are shown in Table 1. The mean heart rate was 143 ± 11.9 beats/min (range 120–169 beats/min). The mean DLP was 236.2 ± 41.3 mGy cm (range 181–327 mGy cm), and the mean effective dose was 21.3 ± 3.6 mSv (range 16.9–29.3 mSv). The mean SSDE was 56.6 ± 14.8 mGy (range 40.6–71.4).

Table 2 summarizes Shaher's coronary classification diagnosed by CT and echocardiography and the comparison with the surgical results. Preoperative CT examination provided highly diagnostic images to identify coronary anatomy

Table 1 Patients' demographic characteristics and radiation dose parameters

Variable	Value
Sex	
Boys	15
Girls	2
Age (days)	5.2 ± 3.0 (1–13)
Weight (g)	2916 ± 424.8 (2110–4019)
Heart rate (beats/min)	143 ± 11.9 (120–169)
Dose-length product (mGy cm)	236.2 ± 41.3 (181–327)
Effective dose (mSv)	21.3 ± 3.6 (16.9–29.3)

Values are mean ± SD with ranges in parentheses

Table 2 Shaher's classification confirmed by surgery and diagnostic accuracy

Shaher's classification	No.	Diagnostic accuracy on CT	Diagnostic accuracy on TTE
Type 1	7	7/7 (100%)	6/7 (86%)
Type 2	4	4/4 (100%)	0/4 (0%)
Type 3	1	1/1 (100%)	1/1 (100%)
Type 4	2	2/2 (100%)	1/2 (50%)
Type 9	3	2/3 (67%)	0/3 (0%)
Total	17	16/17 (94%)*	8/17 (47%)*

CT computed tomography, *TTE* transthoracic echocardiography
*$p = 0.0078$

in 16 of 17 patients (94%). In one patient, body motion was recorded during CT scanning, resulting in poor image quality. Using echocardiography, accurate preoperative identification of coronary anatomy was difficult in almost half of the patients (8/17 patients). Dual-source CT had a significantly higher diagnostic ability than echocardiography ($p = 0.0078$).

Some typical cases are shown in Figs. 2 and 3.

Discussion

In neonates with TGA, preoperative evaluation of the coronary artery anatomy is clinically important for surgical planning. The present study showed that dual-source CT with ECG-gated retrospective scanning provides more highly diagnostic images of the coronary arteries in neonates than echocardiography.

Coronary artery evaluation using CT has some advantages. First, CT images provide not only the origin and course of the coronary arteries but also their relationships with surrounding cardiovascular anatomy, which enables surgeons to precisely image the morphologic features of complex CHD in three or four dimensions. Second, CT can also describe anomalies of the great vessels, such as pulmonary artery anomalies, pulmonary vein anomalies, a right aortic arch, and a persistent left superior vena cava and aortopulmonary collateral vessels, frequently identified in children with TGA better than echocardiography [17]. Right aortic arch was identified in two patients in the present study. Anomalies of the trachea or spleen are also identified on CT.

On the other hand, CT also has a disadvantage. Exposure to ionizing radiation in young infants introduces radiation-related risks, including the potential development of cancer. In the present study, the effective dose with CT using ECG-gated retrospective scanning was 21.3 ± 3.6 mSv, which is more than 10 times higher than cardiac CT with ECG-gated prospective scanning in neonates conducted in our institute during the same period. This is because the patients in the present study were scanned over multiple cardiac cycles (approximately 10 cycles, 5–7 s), and the image data of all cardiac phases were obtained with retrospective scanning. Scanning over multiple cardiac cycles is important to improve temporal resolution. Retrospective scanning allows reconstruction by multiple phases of the cardiac cycle, which enables the coronary assessment at the best motion-free phase of any portion of a coronary artery of interest. Goo has reported the utility of dual-source CT with ECG-gated prospective scanning in evaluating coronary arteries in pediatric patients [18]. However, prospective scanning is susceptible to unpredictable body movements in neonates. Therefore, we chose retrospective scanning in the present study. Table 3 summarizes the frequency of best motion-free cardiac phase used to evaluate coronary artery in the study. The best motion-free cardiac phase varies depending on each patient. It is possible that obtaining data of all the cardiac phases with retrospective scanning could improve the diagnostic ability. However, high level radiation dose with retrospective scanning is not negligible. Significant reduction of radiation exposure might be achievable by scanning only 30–90%, since coronary artery visualization in the present study was good in 30–40% or 80–90% of the cardiac phases as shown in Table 3. Further studies are needed to minimize radiation exposure of children while maintaining image quality.

In the present study, echocardiography showed 6 (86%) of 7 cases of type 1 coronary variation, whereas 2 (20%) of 10 other coronary anomalies were not detected. Therefore, in clinical situations, echocardiography evaluation should be performed first because it can detect a type 1 coronary course with high probability. CT evaluation should then be considered in the case of a patient with a coronary anomaly other than type 1.

The present study had some limitations. First, CT scanning with intubation seems invasive and excessive. However, intubation and breath-hold by an attendant were

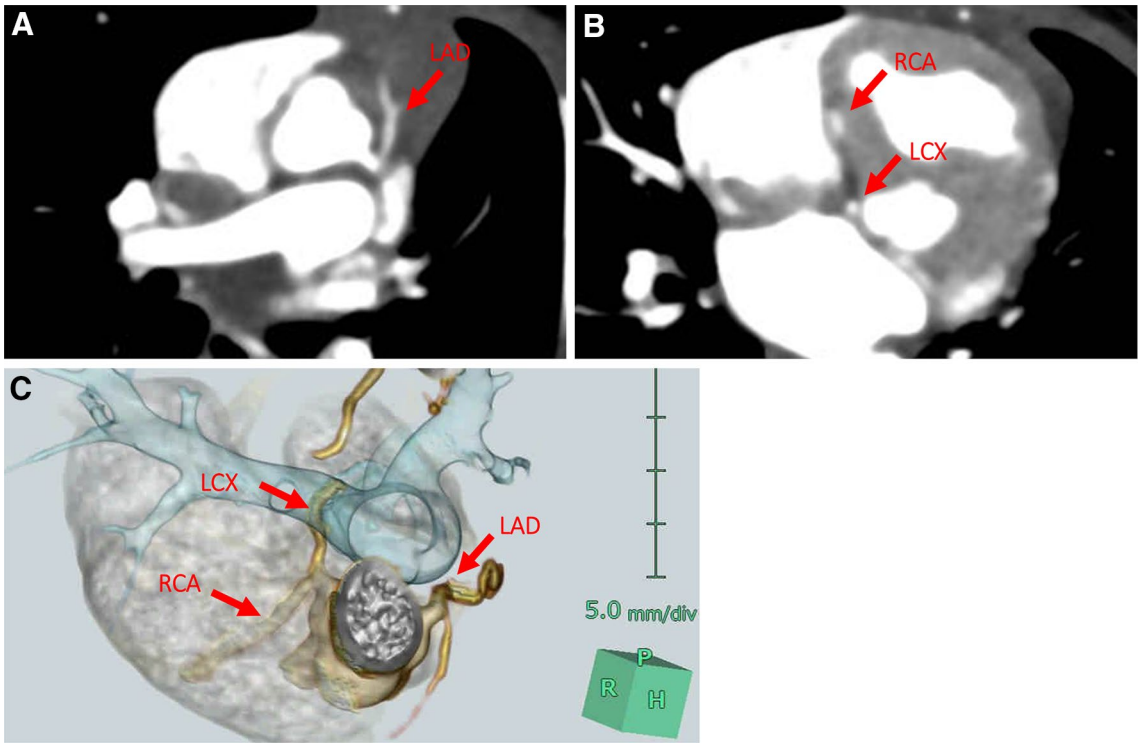

Fig. 2 Dual-source CT with ECG-gated retrospective scanning [axial images (**a**, **b**), volume rendering image (**c**)] shows the left circumflex artery (LCX) as a branch of the right coronary artery (RCA) (Shaher type 2)

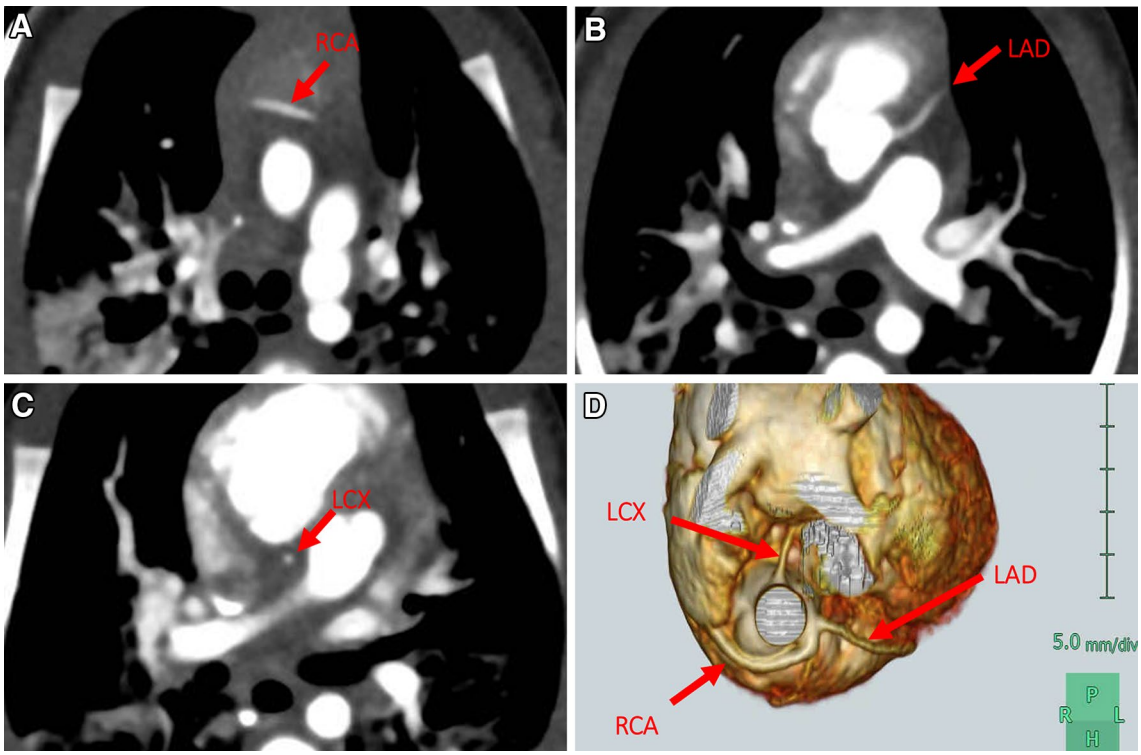

Fig. 3 Dual-source CT with ECG-gated retrospective scanning [axial images (**a**–**c**), volume rendering image (**d**)] shows the left anterior descending artery (LAD) and right coronary artery (RCA) from the left sinus and the left circumflex artery (LCX) from the posterior sinus (Shaher type 4)

Table 3 The frequency of best motion-free cardiac phase

Cardiac phase	Number
30%	2
35%	4
37%	1
40%	1
45%	1
65%	1
80%	3
85%	3
86%	1
Total	17

necessary to obtain motion-free images of the small structures of coronary arteries in neonates. In this study, almost all of the patients (16/17 patients) were intubated during the CT examinations. In 9 patients, intubation had already been performed prior to CT examination to support their respiratory system. Considering their serious situations, CT with intubation could be acceptable. Furthermore, CT investigations are conducted on the closest possible day to the operation to achieve a minimally invasive examination. In the present study, 8 patients remained intubated until the operation in the several subsequent days. Second, the number of subjects was rather small. Further studies with a larger sample size are needed to verify the present findings.

Conclusion

In conclusion, dual-source CT with ECG-gated retrospective scanning is clinically useful in evaluating the coronary arteries in neonates with TGA, since coronary anomalies can be more easily identified with dual-source CT than with echocardiography. Therefore, dual-source CT should be considered when coronary artery assessment by echocardiography is unclear.

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Compliance with ethical standards

Conflict of interest Yamasaki Y: Bayer Healthcare Japan, Modest, Research Grant; Philips Electronics Japan, Modest, Research Grant. Other authors declare that they have no conflict of interest.

Ethical approval Institutional Review Board approval at Fukuoka Children's Hospital was obtained.

Informed consent Written informed consent was waived due to the retrospective nature of the research.

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