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Research article

Preoperative evaluation of anomalous pulmonary venous connection using dual-source computed tomography: Comparison with echocardiography

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ABSTRACT

Purpose: To evaluate the image features and diagnostic agreement for anomalous pulmonary venous connection (APVC) by dual-source computed tomography (DSCT) before surgery when compared with trans-thoracic echocardiography (TTE).

Materials and methods: A total of one hundred and twenty-three patients were enrolled in this study. The associated malformation was analyzed between 39 total anomalous pulmonary venous connections (TAPVC) and 84 partial anomalous pulmonary venous connections (PAPVC). For 75 patients who received surgical treatment, the diagnostic agreement between the surgical findings of DSCT and TTE was evaluated. The dimensions of the four chambers of the heart were also measured by DSCT and TTE.

Results: Atrial septal defect is the most common anomaly associated with APVC (86/123, 69.9%), which has a higher incidence in TAPVC compared to that in PAPVC (100% vs. 56.0%, $p < 0.001$). Of 75 operative patients, discrepancies in diagnostic sensitivity existed between DSCT and TTE for different drainage sites, supracardiac (94.4% vs. 82.2%, $p = 0.001$), cardiac (98.7% vs. 91.1%, $p = 0.089$), and infracardiac (100% vs. 57.1%, $p = 0.096$), respectively, and for different venous origins, right superior pulmonary vein (98.4% vs. 87.1%, $p = 0.871$), right inferior pulmonary vein (100% vs. 87.3%, $p = 0.006$), left superior pulmonary vein (100% vs. 93.1%, $p = 0.246$), left inferior pulmonary vein (100% vs. 95.7%, $p = 0.500$), and atypical pulmonary vein (66.7% vs. 44.4%, $p = 0.011$), respectively. Good agreement was obtained between DSCT and TTE for measurements of left atrium, left ventricle, right atrium, and right ventricle sizes (bias 0.3 ± 5.05 mm, -0.3 ± 4.50 mm, 5.8 ± 14.15 mm, and 1.1 ± 5.95 mm, respectively).

Conclusions: DSCT can provide optimal and accurate anatomy details for patients with APVC, and serves as a promising accessary imaging modality after TTE to achieve a better and comprehensive preoperative imaging evaluation.

1. Introduction

Anomalous pulmonary venous connection (APVC) is a rare congenital heart disease, in which pulmonary veins drain into a systemic vein or the right atrium rather than into the left atrium. Anatomical presentations may vary from mild single partial anomalous pulmonary venous connection (PAPVC) to severe obstructed total anomalous pulmonary venous connection (TAPVC) [1]. The symptoms most commonly associated with APVC are respiratory distress, decreased exercise tolerance, and subsequent circulatory collapse [2,3]. Surgical treatment offers the only means to prevent progression of the disease; however, high operative mortality rates have been reported, due to the complexity of surgery [4–8]. Therefore, an appropriate imaging modality is needed to optimize preoperative planning in order to decrease surgical risk.

Cardiac catheterization has long been regarded as the gold standard imaging modality for congenital heart disease [9]. However, it may be not the best chosen because of exist high radiation dose and associated anesthesia-related risks [10]. Furthermore, iatrogenic venous obstruction due to catheter-related injuries cannot be ignored in APVC [11]. Trans-thoracic echocardiography (TTE) is regarded as the diagnostic modality of choice in patients with APVC, but diagnostic accuracy depends largely on the skills and working experience of the operator, as well as the size and quality of the acoustic window [1]. Cardiac

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magnetic resonance imaging (CMR) may not always be an option due to the lengthy examination time, need for sedation, and expense although the procedure does not involve radiation exposure [12].

Featuring high spatial and temporal resolution, dramatic decrease in radiation dose, excellent image quality, and powerful image post-processing, dual-source computed tomography (DSCT) has been widely used in complex congenital heart disease [11,13–15]. To the best of our knowledge, few large-scale studies have focused on DSCT use for APVC [16–18]. Therefore, we enrolled 123 patients to evaluate the image features and diagnostic agreement of DSCT with TTE for different types of APVC before surgery.

2. Materials and methods

2.1. Study population

From January 2012 to November 2016, 126 patients' imaging data whose clinical diagnosis was APVC were retrospectively reviewed. The inclusion criterion was confirmed imaging findings of APVC according to ACC/AHC guidelines [19]. TAPVC refers to all pulmonary veins are anomalously connected to the right atrium or to the systemic venous circulation; PAPVC refers to at least one, but not all, pulmonary veins connect to a location other than the left atrium [1]. Patients who were hypersensitivity to iodinated contrast medium (n = 1) or whose imaging examination results were unavailable were excluded (n = 2). Finally, a total of 123 patients (59 males and 64 females with an average age of 24.94 ± 22.07 years, range from 1 month to 76 years) were enrolled. Among these patients, 75 patients received surgical treatment and underwent both DSCT and TTE preoperatively. This retrospective study was approved by the institutional review board of our hospital (No. 14-163), and written informed consent was obtained from all patients, including radiation exposure and adverse reactions to the iodinated contrast agent. All patient-sensitive information was protected with full confidentiality and only used for the purposes of this study.

2.2. Dual-source computed tomography

All examinations were performed on second generation DSCT scanner (Somatom Definition; Siemens Medical Solutions, Forchheim, Germany). Patients under 7 years of age were administrated with a short-term sedation intravenously (chloral hydrate, concentration: 10%, 0.5 ml/kg) to help with breath control (n = 37). The scans were performed in a cranio-caudal direction from the aortic arch to the apex of the heart. The protocol parameters were as follows: tube voltage of 80–120 kV (adapted to body mass index), weight-adapted setting for tube current, gantry rotation time of 0.28 s, and pitch of 0.2–0.5 (adapted to heart rate). Nonionic contrast agent (iopamidol 370 mg/ml; Bracco, Italy) was injected at a flow rate of 1.2–3.0 ml/s via peripheral veins, followed by 20 ml of saline solution at the same flow rate. Bolus tracking was used for data acquisition from the region of interest in the descending aorta with a predefined threshold of 100 HU. The images were reconstructed with a slice thickness of 0.75 mm and an increment of 0.7 mm using a medium smooth-tissue convolution kernel (B26f). All images were transferred to an external workstation (Syngo MultiModality Workplace) for further analysis. The multiplanar reformation, maximum intensity projection and volume rendering were used for image interpretation.

2.3. Trans-thoracic echocardiography

Standard TTE was performed in all subjects using a commercially available system (iE33; Philips Medical Systems NA, Bothell, WA, USA). The examination (including M-mode, two-dimensional, continuous wave and Doppler color flow imaging) was performed according to the recommendations of the American Society of Echocardiography Committee [20].

Table 1
Baseline characteristics of APVC patients (n = 123).

	TAPVC(n = 39)	PAPVC(n = 84)	P value
Age, year	7.77 ± 12.22	33.27 ± 23.07	0.000
Male gender(male:female)	21:18	38:46	0.374
Weight(kg)	18.35 ± 19.87	44.85 ± 21.16	0.000
Height(cm)	91.73 ± 40.25	143.29 ± 34.18	0.000
Associated Malformations			
ASD	39(100%)	47(56.0%)	0.000
VSD	1(2.6%)	1(1.2%)	0.535
Persistent left superior vena cava	4(10.3%)	5(6.0%)	0.463
Triatrial heart	1(2.6%)	2(2.4%)	1.000
UCSS	1(2.6%)	0(0%)	0.317
Right lung dysplasia	0(0%)	2(2.4%)	0.465
Azygos lobe	0(0%)	1(1.2%)	0.683
Heterotaxy syndrome	1(2.6%)	0(0%)	0.317

Numbers in bracket represent the percentage of subject for associated malformations.
APVC, anomalous pulmonary venous connection; TAPVC, total anomalous pulmonary venous connection; PAPVC, partial anomalous pulmonary venous connection; UCSS, unroofed coronary sinus syndrome; ASD, atrial spetal defect; VAD, ventriclar spetal defect.

Table 2
Diagnostic agreement of anomalous pulmonary vein refer to surgery (n = 75).

	surgery	modality		
		TTE	CT	P value
Drainage sites				
supracardiac	101	83(82.2%)	95(94.4%)	0.001
cardiac	79	72(91.1%)	78(98.7%)	0.089
infracardiac	7	4(57.1%)	7(100%)	0.096
Origins				
RSPV	62	54(87.1%)	61(98.4%)	0.871
RIPV	55	48(87.3%)	55(100%)	0.006
LSPV	29	27(93.1%)	29(100%)	0.246
LIPV	23	22(95.7%)	23(100%)	0.500
Atypical PV	18	8(44.4%)	12(66.7%)	0.011
Stenosis	9	8(88.9%)	9(100%)	0.500
Vertical vein				
finding	21	19(90.5%)	21(100%)	0.244
stenosis	6	4(66.7%)	6(100%)	0.227
Associated malformations				
ASD	59	58(98.3%)	56(94.9%)	0.051
VSD	2	2(100%)	1(50%)	0.500
USCC	1	1(100%)	0(0%)	0.500
PLSVC	7	5(71.4%)	7(100%)	0.231

Numbers in bracket represent the percentage of subject. P-values < 0.05 were regarded as statistical significance between DSCT and TTE.
RSPV, right superior pulmonary vein; RIPV, right inferior pulmonary vein; LSPV, left superior pulmonary vein; LIPV, left inferior pulmonary vein; Atypical PV, additional veins with independent junctions to systemic circulation separate from the four-PVs or confluence pulmonary veins; PLSVC, persistent left superior vena cava.

2.4. Image analysis

All images were retrospectively assessed by one cardiac radiologist (DSCT) or one cardiologist (TTE) with more than 5 years' experience and both were unaware of surgical findings or other imaging results.

For DSCT, the morphological features (course of all individual pulmonary veins and associated intra- and extra-cardiac malformations) and quantitative features (the size of cardiac chambers and vertical vein) of APVC were displayed and recorded. Using computer calipers, cardiac chamber sizes were measured in the same planes as TTE. The diameter of the vertical vein was acquired at the level of the ipsilateral pulmonary artery by three-dimensional reconstruction [21]. Anomalous pulmonary veins were considered to be obstructed if the cross-sectional area of the pulmonary vein or draining vein was reduced