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Original Article

Diagnostic advantage of 64-slice spiral CT angiography in preoperative diagnosis of anomalous pulmonary venous connection

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Abstract: *Purpose:* Anomalous pulmonary venous connection (APVC) is a rare congenital heart anatomical deformity. 64-slice spiral CT angiography (64-SSCTA) has been widely used in cardiovascular examination. However, research on 64-SSCTA in APVC is not much. This paper aimed to study the diagnostic advantage of 64-SSCTA and three-dimensional reconstruction in patients with APVC. *Methods:* From 2009 to 2015, 83 segments of pulmonary vein of anomalous drainage in 22 patients confirmed by surgery were analyzed. All patients underwent transthoracic echocardiography (TTE) at 48 hours before 64-SSCTA enhanced scan, followed by three-dimensional reconstruction in the workstation. 64-SSCTA and TTE results were compared with surgery results respectively. *Results:* The difference between 64-SSCTA and the surgery results was not statistically significant (P = 0.155), but the difference between TTE and the surgery results was statistically significant (P = 0.001). 64-SSCTA (Pearson test r = 0.892, Kappa value = 0.714, accuracy was 97.6%) was strongly related to the surgery results, and the TTE (Pearson test r = 0.347, Kappa value = 0.537, accuracy was 86.7%) was slightly related to the surgery results. *Conclusion:* In the diagnosis of ectopic drainage pulmonary vein of complex congenital heart disease, 64-SSCTA and 3D reconstruction have good consistency with operation control (Kappa value = 0.714, P<0.001), could be used as a good noninvasive examination method in the preoperative assessment of the deformity.

Keywords: Anomalous pulmonary venous connection, congenital heart disease, tomography, X-ray computer

Introduction

Anomalous pulmonary venous connection (APVC) is a rare congenital heart anatomical abnormalities, It refers to the fact that the pulmonary veins do not normally drain into the left atrium, but drain into the right atrium or the venous system [1]. APVC is often associated with atrial septal defects and other cardiovascular malformations. And the incidence of APVC accounts for 5.8% of congenital heart disease [2].

During embryonic development, pulmonary venous connection anomaly doesn't participate in fetal blood circulation because of higher pulmonary artery pressure [3]. At birth, as the pulmonary artery pressure drops and the pulmonary blood flow increases, the hemodynamic imbalance persists, and the severity of the symptoms depends on the size of the pulmonary artery pressure [3]. The pulmonary artery pressure is determined by the location of pulmonary venous heterotopic drainage, the diameters of the ectopic drainage pulmonary venous confluence, the presence of confluence of each pulmonary vein stenosis, and the size of atrial septal defect [4]. And accompanied by other heart abnormalities may make the patient's pathophysiology and clinical manifestations even worse [4]. The presence and extent of pulmonary vein obstruction is an important factor in the diagnosis and treatment of APVC [5]. Cardioangiograpy (CAG) is still recognized as the gold standard for the diagnosis of APVC, but it is an invasive operation and potentially dangerous. The amount of contrast agent of CAG is large, the inspection time is long, the amount of

Table 1. General characteristics of the 22 patients

General characteristics	N (%)
Man/Woman	13/9
Age range	36 day-29 years
Median age (25%, 75%)	14.5 (5.56, 57.96) months
<5 years	17 (77.3%)
≥5 years of age	5 (22.7%)
PAPVC	3 (13.6%)
PAPVC (intracardiac type)	3 (13.6%)
TAPVC	19 (86.4%)
TAPVC (intracardiac type)	9 (40.9%)
TAPVC (supracardiac type)	9 (40.9%)
TAPVC (hybrid type)	1 (4.5%)

Partial anomalous pulmonary venous connection (PAPVC), total anomalous pulmonary venous connection (TAPVC).

X-ray radiation is large [6], anesthesia technology needs to be used, and it is affected by the position, and influence on infants and patients with heart failure are limited, especially for patients with obstructed total APVC, the risk of detection is greater. With the development of medical imaging and surgical techniques, the majority of patients with APVC can survive to adulthood, which requires the correct preoperative diagnosis, disease assessment, and perfect operation to minimize the morbidity [7]. 64-slice spiral CT angiography (64-SSCTA) has been widely used in cardiovascular disease examination; it has many advantages, including noninvasive, fast scanning speed, wide range, high spatial resolution and powerful post-processing advantages [8]. Comprehensive use of various accurate post-processing images can be very good to show the structure of the anatomy of the heart and the arteriovenous connection, which are very important for the preoperative assessment of children with complex congenital heart disease [9]. Accurate diagnosis of APVC is critical for the development of a good preoperative planning. This paper focused on the applicability of 64-SSCTA in preoperative diagnosis of APVC, and tried to provide a clear idea for an accurate preoperative clinical diagnosis of APVC.

Materials and methods

General information

From 2009 to 2015, 22 patients were confirmed to be with APVC in our hospital, including 13 males and 9 females, aged from 36 days to 29 years old, the median age was 435 days, these patients were included in this retrospective study. The basic information of patients were placed in **Table 1**. This study was approved by the ethics committee of our hospital, all patients or their parents had signed the informed consent.

Imaging protocols of 64-SSCTA

Transthoracic echocardiography (TTE) examination was carried out in all patients 48 hours before 64-SSCTA checks. Patients fasted for 4-6 h before 64-SSCTA check. For patients whose age <5-year-old or patients couldn't cooperate, chloral hydrate sedation were given before the examination, and the sedation were good without the use of anesthetic techniques. For patients who couldn't breathe in the way of doctor's request, breathing exercise were performed before the test, so as to better breath-hold scan. All patients were treated with Philips Brilliance 64-slice CT scanners, non-ECG-gated scans, and non-ionic contrast medium iohexol (370 mg iodine/ml) was used as contrast agent, its dose was measured by 1.5 ml/kg weight, and additional saline was added. Injected with a double pressure syringe, and the flow rate was about 1.5-3.5 ml/s. If the contrast medium was injected intravenously through the arm or scalp, the scan delay time was 18-20 s, and the scan delay time was 20-22 s by injecting the contrast agent through the dorsal vein of the foot. Compared with adults, the scan delay time of infants and young children was shorter (because the cycle time was short, the heart rate was rapid).

For patients with intravenous injection of contrast agent through the arm or scalp, they were scanned in the foot-to-head direction. And for patient was injected with contrast agents in the dorsal foot vein, they were scanned from the head to the direction of the foot, to avoid high artifacts in the inferior vena cava caused by contrast agent with high concentration, which may cause interference to surrounding tissue structures. The exposure time was 2-5 s.

Scanning range from the thoracic inlet to the lower edge of the liver, the scan parameters of Infant were 80 KV, 200-250 mAs; 120 kV, 150 mAs in adult, the slice thickness was 5 mm, the restructuring thickness was 0.625 mm. CT vol-

Table 2. 64-SSCTA, TTE and the operation results for APVC

Malformation type	Operation	64-SSCTA	TTE
PAPVC	7 (8.4%)	7 (8.6%)	7 (9.7%)
Intracardiac type	7 (8.4%)	7 (8.6%)	7 (9.7%)
TAPVC	76 (91.6%)	74 (91.4%)	65 (90.3%)
Intracardiac type	36 (43.4%)	35 (43.2%)	34 (47.2%)
Supracardiac type	36 (43.4%)	35 (43.2%)	30 (41.7%)
Hybrid type	4 (4.8%)	4 (4.9%)	1 (1.4%)
Total	83	81	72

The data shown in the table is the number of abnormal drainage pulmonary vein. Partial anomalous pulmonary venous connection (PAPVC), total anomalous pulmonary venous connection (TAPVC), 64-slice spiral CT angiography (64-SSCTA), thoracic echocardiography (TTE).

Table 3. 76 of other heart abnormalities inside and outside which merged with 22 cases of APVC

Malformations	N (%)
Dextrocardia	2 (2.6%)
Dextroversion of the heart	1 (1.3%)
Single atrium	7 (9.2%)
Single ventricle	5 (6.6%)
Atrial septal defect	12 (15.8%)
Ventricular septal defect	3 (3.9%)
Transposition of the great arteries	7 (9.2%)
Double outlet right ventricle	4 (5.3%)
Pulmonary atresia	1 (1.3%)
Pulmonary valve under stenosis	5 (6.6%)
Patent ductus arteriosus	9 (11.8%)
Single coronary artery	1 (1.3%)
Persistent left superior vena cava	4 (5.3%)
Heterotaxia syndrome	7 (9.2%)
Patent foramen ovale	2 (2.6%)
Complete endocardial cushion defect	3 (3.9%)
Partial systemic venous heterotopic drainage	3 (3.9%)
Total	76

ume data were transmitted to AW4.2 workstation, thin layer continuous scrolling image observation were performed, and we finally focused on the lesion, followed by multi-planar reconstruction (MPR), maximum intensity projection (MIP) and volume rendering (VR) to reconstruct. We focused on the location of APVC, and whether there was a vertical vein stenosis in each pulmonary vein and the pulmonary vein confluence, the route of the vertical venous drainage into the venous and other heart malformations associated with surgery.

The axial and meaningful reconstruction image were selected for laser printing. All images were analyzed by cardiovascular radiology doctors who have more than six years of work experience.

Statistical analysis

Count data were compared by chi-square test or Fisher's exact test. Pearson test was performed to compare the correlation of 64-SSCTA and TTE results with surgery results in the discovery of APVC, respectively. Kappa test was used to evaluate the consistency of 64-SSCTA and TTE results with surgery results in the check of abnormal drainage on the pulmonary vein, respectively. All statistics were performed in IBM SPSS 20.0 (Chicago, Illinois) software, $P<0.05$ was considered statistically significant.

Results

Of the 22 patients, 83 of APVC were confirmed by surgery. Of the 76 (91.6%) total anomalous pulmonary venous connection (TAPVC), 36 (43.4%) of supracardiac type, 36 (43.4%) of intracardiac type, 4 (4.8%) of hybrid type were included; of the 7 (8.4%) partial anomalous pulmonary venous connection (PAPVC), 7 (8.4%) of intracardiac type were included.

The diagnostic accuracy of 64-SSCTA and TTE were 97.6% and 86.7%, respectively. X^2 test results showed that the difference between 64-SSCTA and the surgery results was not statistically significant ($P = 0.155$), but the difference between TTE and the surgery results was statistically significant ($P = 0.001$). Pearson test results showed that 64-SSCTA (Pearson test $r = 0.892$, $P<0.001$) was strongly related to the surgery results, but TTE (Pearson test $r = 0.347$, $P = 0.026$) was slightly related to the surgery results. The Kappa value between surgery results and TTE results was 0.537 ($P< 0.001$). The Kappa value between surgery results and 64-SSCTA was 0.714 ($P<0.001$). 64-SSCTA, TTE and the surgery results for APVC were shown in **Table 2**.

22 cases of congenital heart disease, merged with 76 of other heart abnormalities inside and

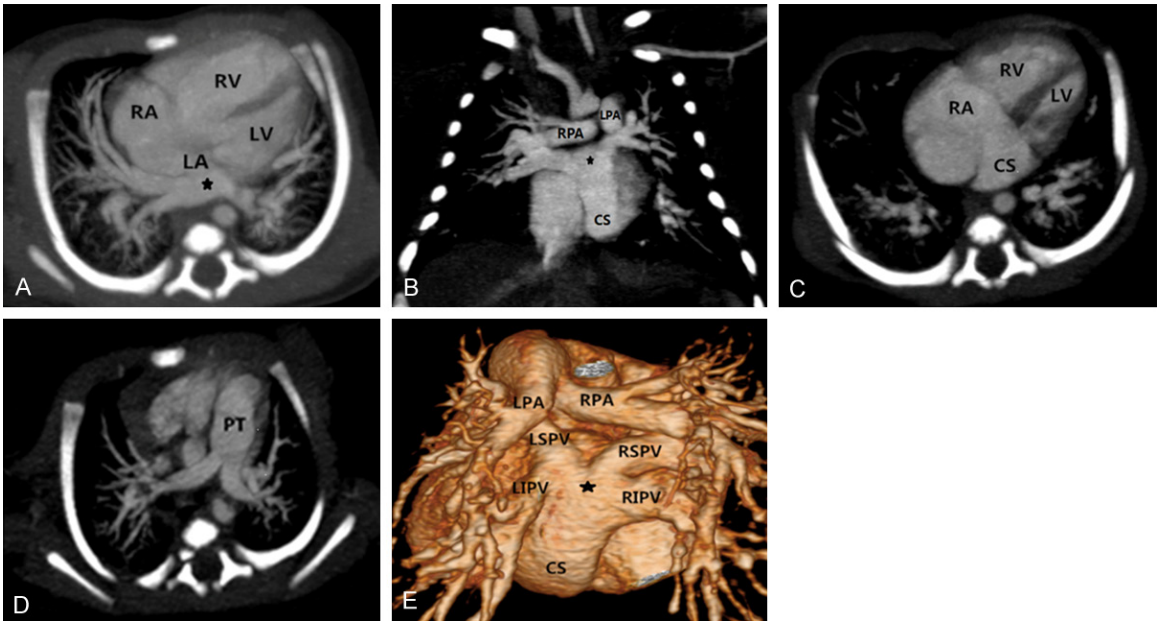

Figure 1. A 36 days boy with total anomalous pulmonary venous connection (intracardiac type), atrial septal defect, pulmonary hypertension. 64-SSCTA after processing (A) MPR axial (B) MPR coronal and (C and D) axial maximum intensity projection image displayed four pulmonary vein confluence (*) was located behind the left atrium, led into the coronary sinus, and finally back into the right atrium. Right atrial chamber expanded significantly, the expansion of the main pulmonary artery, right and left pulmonary artery clearly displayed. (E) VR reconstructed image of the same patient clearly showed: after cardiac four pulmonary veins intersection point (*) and finally leading into the enlarged coronary sinus. Significant expansion of the pulmonary trunk, the right and the left pulmonary artery could be clearly displayed. pulmonary trunk (PT), coronary sinus (CS), left atrium (LA), right or left pulmonary artery (RPA or LPA), four pulmonary veins confluence (*).

outside, wherein 2 (2.6%) of dextrocardia, 1 (1.3%) of dextroversion of the heart, 7 (9.2%) of single atrium, 5 (6.6%) of single ventricle, 12 (15.8%) of atrial septal defect, 3 (3.9%) of ventricular septal defect, 7 (9.2%) of transposition of the great arteries, 4 (5.3%) of double outlet right ventricle, 1 (1.3%) of pulmonary atresia, 5 (6.6%) of pulmonary valve under stenosis, 9 (11.8%) of patent ductus arteriosus, 1 (1.3%) of single coronary artery, 4 (5.3%) of persistent left superior vena cava, 7 (9.2%) of Heterotaxia syndrome, 2 (2.6%) of patent foramen ovale, 3 (3.9%) of complete endocardial cushion defect, 3 (3.9%) of partial systemic venous heterotopic drainage (**Table 3**).

Discussion

64-SSCTA has many advantages, such as safe, non-invasive, fast scanning speed, wide range, without overlapping. Isotropic volume data could be obtained by 64-SSCTA, in addition, contrast agent of 64-SSCTA was less, temporal and spatial resolution was high. Axial thin scan images was used in 64-SSCTA and accompanied with a variety of three-dimensional scan images could meet the needs of clinical diagnosis [10]. Compared with two-dimensional images, it could better assess the patient's deformity from different angles and plane, 64-SSCTA can accurately display joints and travel direction from four veins to the right atrium or the venous system. The anomalous pulmonary venous drainage showed unilateral or bilateral, partial or whole pulmonary veins with single or few branches into the right atrium, the coronary sinus or the superior and inferior vena cava and its branches.

According to the number of pulmonary venous drainage, APVC is divided into TAPVC and PAPVC. According to the connection site of pulmonary venous, the right atrium and the venous system, TAPVC and PAPVC are divided into intracardiac type (**Figure 1A-E**), supracardiac-type (**Figure 2A-D**), infracardiac type, hybrid type and supracardiactype, intracardiac type (**Figure 3A-E**), infracardiac type, respectively.

In addition, the scan time of 64-SSCTA was short, it could significantly reduce the respiratory and cardiac artifacts. 64-SSCTA has more

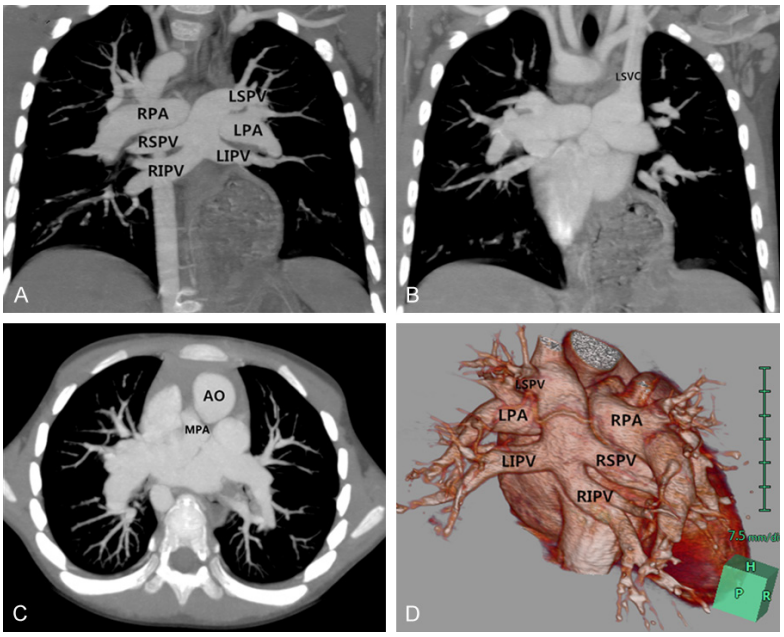

Figure 2. A 5 years old boy with total anomalous pulmonary venous connection (supracardiac type), dextrocardia, ectopic aorta, pulmonary stenosis. 64-SSCTA after processing (A, B) Coronal maximum intensity projection, (C) axial maximum intensity projection image, (D) VR reconstruction image showed four pulmonary veins formed a common trunk draining into the root of left superior vena cava, the main pulmonary artery (MPA) poorly developed, In front of the aorta and pulmonary artery in the back, ectopic artery. Right ventricle (RV); aorta (Ao); left atrium (LA); right atrium (RA); right or left superior pulmonary vein (RSPV or LSPV); right or left inferior pulmonary vein (RIPV or LIPV) left superior vena cava (LSVC).

clinical practicality for patients who couldn't cooperate, infants who must confirm the diagnosis situation of APVC and patients who are not suitable for cardiac catheterization angiography. For this reason, the localized and qualitative diagnostic of APVC is important. In this study, this important image information had been confirmed by surgery, so we could use this information to guide surgery accurately, to develop a reasonable operative plan. In earlier studies, the use of cardiac CTA in pediatric patients were considered to be limited [11], but recent studies have shown that in neonatal and infant patients with APVC, 64-SSCTA examination could provide very useful information, Furthermore, 64-SSCTA was superior to TTE in assessing of APVC [5, 12-13]. Oh *et al.* [5] found that the sensitivity and specificity in the diagnosis of 23 newborns with APVC were 100% and 100%, respectively. But the sensitivity of TTE in verifying the position of anomalous pulmonary venous confluence, path of vein-shaped and vein stenosis, were 87%, 71% and 0%, respectively. In other studies, Shen *et al.* and Kim *et al.* [12, 13] also found that the consistency between 64-SSCTA and surgery in the diagnosis of APVC was 100%, but only 61% between ultrasound and surgery. In this study, 64-SSCTA (Kappa value = 0.714, P< 0.001) have higher consistency than TTE (Kappa value = 0.537, P<0.001) in the comparison of the surgery results.

Compared with cardiac catheterization angiography, 64-SSCTA basically requires mild transient sedation, without anesthesia, and the radiation hazards are greatly reduced. Compared with ultrasound, magnetic resonance as well as traditional cardiac catheterization angiography, 64-SSCTA can provide the most comprehensive assessment of the lesion in thorax and upper abdomen of the patient. 64-SSCTA can not only accurately assess the morphology of excardiacvascular changes, but also accurately evaluate the diffuse parenchymal lung disease, trachea dysplasia, et al. Many problems of morphological abnormalities could be checked by a one-stop check. In order to avoid unnecessary radiation exposure of the patient, we adopted a non-ECG-gated scans. To observe the atrioventricular anatomy and connection with great vessels, non-ECG-gated imaging diagnosis technique could meet our requirements. But if to assess the anatomical details of the structure inside the heart and coronary artery, the application of ECG gating technique was necessary, In this study, the morphology of the pulmonary vein, and the way of connections were all been explored, non-cardiac gating techniques fully met the requirement to assess the preoperative lesions for radiology and cardiac surgeon doctor [7, 14].

In addition, Cheng *et al*. showed that 64-SSCTA was also a good noninvasive procedure in the postoperative follow-up. The image of 64-SSCTA

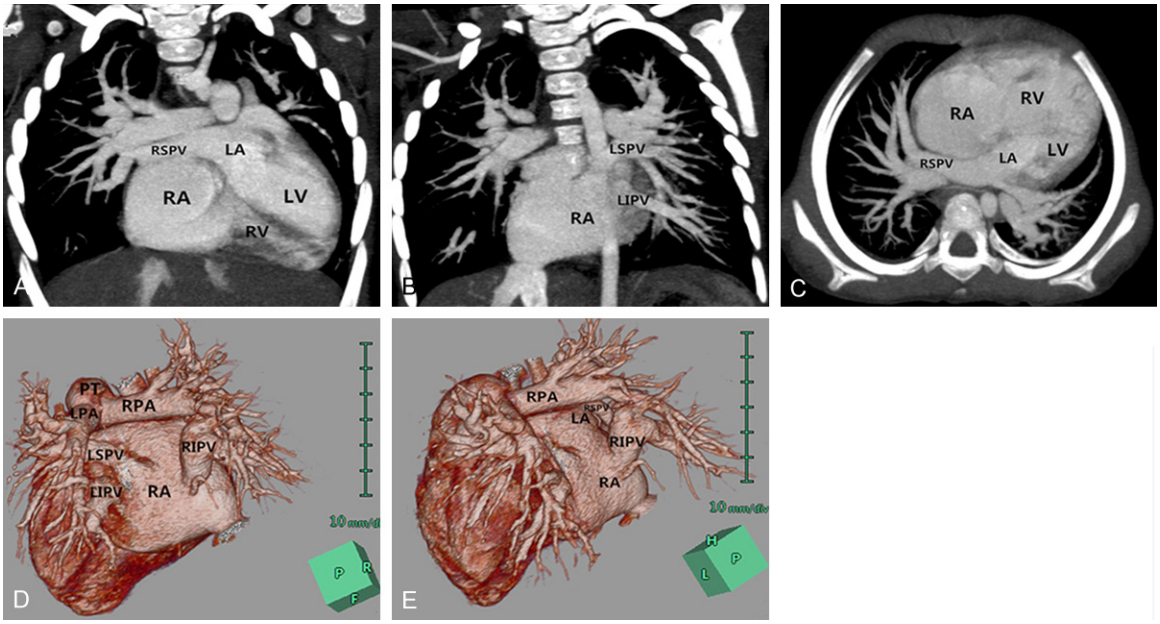

Figure 3. A 20-month-old girl with partial anomalous pulmonary venous connection (intracardiac type). The right atrial expanded significantly, two left pulmonary vein and the right inferior pulmonary vein draining into the right atrium and right superior pulmonary venous returning into the left atrium, pulmonary artery significantly expansion. Post-processing of 64-SSCTA (A, B) Coronal maximum intensity projection, (C) axial maximum intensity projection image, (D, E) VR reconstruction image showed two left pulmonary veins (LSPV, LIPV) and right inferior pulmonary vein (RIPV) led into the right atrium, right superior pulmonary vein (RSPV) draining into the left atrium. Right atrial expanded significantly, dilated pulmonary trunk, the right and the left pulmonary artery could be clearly displayed.

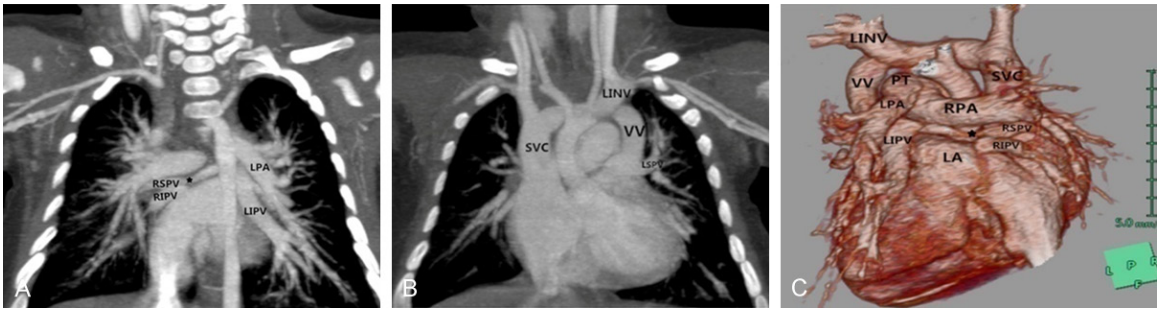

Figure 4. A 79 days boy with total anomalous pulmonary venous connection (supracardiac type), two right pulmonary vein confluence (*) stenosis, pulmonary venous confluence distal obstruction. Post-processing of 64-SSCTA (A, B) Coronal maximum intensity projection, (C) VR reconstruction image showed two right pulmonary veins merged into a common trunk, the confluence (*) stenosis, and the two left pulmonary veins together by vertical vein (VV) leading into the left innominate vein (LIV), and finally into the superior vena cava (SVC). Right atrial and ventricular chamber significantly expanded, dilated pulmonary trunk (PT), the right and the left pulmonary artery could be clearly displayed.

clearly shows whether the pulmonary veins connected to the left atrium accurately, whether there are pulmonary vein obstruction, stenosis and other cardiac malformations. Therefore, 64-SSCTA is an ideal evaluation tool for post operation of APVC [15]. The risk factors and major complications which can lead to death after postoperative APVC are pulmonary venous obstruction, pulmonary hypertension, pulmonary vein insufficiency, and possible cardiac involvement. Anastomotic stenosis, pulmonary vein hypoplasia and pulmonary vein thrombosis could be discovered by 64-SSCTA. Pulmonary hypertension can be quantificational evaluated by three-dimensional reconstruction MPR and curved surface reconstruction of the dilated pulmonary arteries. In addition, some heart disease lesion involved can also be

observed. 64-SSCTA is superior to echocardiography in the observation of the paths of APVC, abnormal position of the pulmonary venous confluence and some postoperative complications (anastomotic stenosis, hypoplasia of the pulmonary veins and venous thrombosis) [16, 17].

The type and extent of pulmonary venous obstruction determines the degree of pulmonary hypertension and heart failure [18]. Approximately 50% of patients with APVC symptoms occur in the neonatal period, and most patients died at the infant stage because they did not have immediate surgery. [19]. Pulmonary venous obstruction can occur in any type of APVC, but the most important is the occurrence of the infracardiac type of APVC [20, 21]. The most important factors which affecting the survival of these patients are the size of atrial septal defect and the presence of normal or near-normal pulmonary artery pressure [18]. Therefore, preoperative and accurate diagnosis of pulmonary venous drainage is necessary, operation is also the main way to treat APVC. With the constant improvement of the imaging diagnosis, it is more accurate to display the extra vascular cardiac malformation of complex congenital heart disease, can improve the accuracy of the operation to reduce postoperative mortality [20].

Echocardiography is inexpensive, easy to check, no radiation, high resolution for heart malformations, accurate diagnosis and it is able to evaluate cardiac function and hemodynamics. But the density and spatial resolution of echocardiography are obviously lower than 64-SSCTA. It is more difficult to make clear diagnosis localization for abnormal connections pulmonary vein. This study showed that there were significant difference ($P = 0.018$) between echocardiography and 64-SSCTA in the diagnosis of APVC. Echocardiography is not very good to observe the location and travel direction of APVC, it cannot provide intuitive stereoscopic image to the surgeon [22].

Cardiac catheterization is used to as a traditional supplement to the lack of diagnostic ultrasound inspection method. It can provide hemodynamic information, clear the bony structure through the digital subtraction technique, so as to reduce the influence of artificial motion artifacts. In addition, cardiac catheterization angiography also has potential negative effects, anesthetic technique is needed, and the operation is invasive, the amount of radiation is large and it's expensive. It could cause death from cardiac arrest in those patients with severe cyanosis and obstruction pulmonary venous drainage. So cardiac catheter angiography is necessary for patients who require hemodynamic information or interventional diagnosis treatment.

64-SSCTA can basically replace invasive cardiac catheterization angiography in the display of pathological anatomy. For children with congenital heart disease, 64-SSCTA is able to make the correct diagnosis of APVC, the processed image can intuitively reflect the lesions in three-dimensional, and can reflect the presence and site of obstruction of APVC (**Figure 4A-C**) to some extent, but cannot reflect the degree of obstruction [12]. As an evaluation of pulmonary vein anatomy of an unusual connection and noninvasive methods, MRI (magnetic resonance imaging) and MRA(Magnetic resonance angiography) have been used for many years. The advantages of MRI and MRA include multi-plane observation, no ionizing radiation, and the ability to rapidly capture contrast media to obtain dynamic images at different blood vessel phases. MRI and MRA can successfully display and accurately diagnose APVC. MRI and MRA have the advantages of non-invasive, no radiation and multi-faceted benefits, and they are able to check the heart function, they are also effective ways to diagnose this disease. But the scan time is long, the sedation is higher, the resolution is not ideal, the metal implants cannot be accepted, and pediatric examination is more restricted.

In short, 64-SSCTA has great advantages in the diagnosis of pathological anatomy of congenital heart disease patients with APVC [23]. Correct morphological information can be obtained objectively, and cardiac structural abnormalities can be detected effectively. 64-SSCTA provides a detailed image information for the development of accurate clinical treatment programs, selection procedure. In combination with echocardiography, 64-SSCTA can significantly increase the diagnostic accuracy of malformation of complex congenital heart disease, and cardiac function can be fully evaluated, but to comprehensively and accu-

rately evaluate the degree of pulmonary venous obstruction, cardiovascular angiography is still needed. This required us to further study.

Our study reveals that, 64-SSCTA is not only an accurate preoperative diagnosis method for complex congenital heart disease patients with APVC, but also a convenient method to find complications in the postoperative follow-up.

Disclosure of conflict of interest

None.

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