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*Article*

# Clinical Application of Echocardiography Combined with CT Angiography in the Diagnosis of Total Anomalous Pulmonary Venous Connection in Children

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## Abstract

**Background**: Total anomalous pulmonary venous connection (TAPVC) is a serious congenital heart defect, and the accuracy of its diagnosis has a significant impact on surgical planning and prognosis. In this study, we systematically evaluated the feasibility of echocardiography combined with angiography in the diagnosis of abnormal locations of TAPVC. **Methods**: This retrospective cohort study aims to evaluate the clinical utility of echocardiography in the preoperative diagnosis of TAPVC in children. A total of 105 pediatric patients who underwent corrective TAPVC surgery at the Hunan Children's Hospital were included. A combined echocardiography, and CT angiography (CTA), diagnosis was compared. The effects of echocardiography and CTA on the type of TAPVC, the auxiliary diagnosis of cardiac malformations, and the details of TAPVC on surgery were evaluated separately. **Results**: The positive diagnosis rate of TAPVC after combined echocardiography and CTA was 100%, and the type of TAPVC was supracardiac in 46 cases, intracardiac in 33 cases, subcardiac in 14 cases, and mixed in 12 cases. The diagnostic rate of echocardiography was 82.86%, which was lower than that of CTA (94.29%). The combined diagnosis method had the highest diagnosis rate of 100% ($p < 0.05$). The correct recognition rate of echocardiography in the diagnosis of heart-related malformations (91.43%) was lower than that of CTA (97.14%), and the correct recognition rate of combined diagnosis was 100% ($p < 0.05$). Two independent cardiologists evaluated the imaging approach based on the clarity of the images, the level of detail, and their support for the surgical plan. There was no statistically significant difference between the two methods ($p > 0.05$). **Conclusions**: Echocardiography and CTA have high accuracy and clinical value in the preoperative diagnosis of TAPVC in children, respectively, and echocardiography combined with CTA plays an important role in the diagnosis of TAPVC, related cardiac malformations and preoperative evaluation, and the selection of imaging examination methods should be based on specific clinical conditions.

## Keywords

echocardiography; CT angiography (CTA); total anomalous pulmonary venous connection; pulmonary veins

## Introduion

Total anomalous pulmonary venous connection (TAPVC) is a serious congenital heart defect that accounts for about 3% of cases of congenital heart disease [1]. It typically presents with a failure of the pulmonary veins to drain normally to the left atrium and instead to abnormal drainage to the systemic venous system or the right atrium [2,3]. This abnormality leads to obstruction of pulmonary venous return, leading to severe cardiac and respiratory symptoms [4]. Early and accurate diagnosis of TAPVC is essential for effective surgical planning and improved postoperative outcomes.

Echocardiography, as a non-invasive imaging modality, has played an important role in the diagnosis of pediatric heart disease in recent years [5]. Echocardiography uses ultrasound waves to explore the heart and observe the anatomy and functional status of the heart by receiving the reflected sound waves and converting them into images [6]. Because echocardiography has the advantages of being non-invasive, simple and easy to perform, and high in accuracy, it is widely used to diagnose cardiovascular diseases in children. For example, echocardiography can provide a detailed evaluation of complex structural abnormalities such as TAPVC, atrial septal defect, and ventricular septal defect in congenital heart disease [7]. Studies have shown that echocardiography has high sensitivity and specificity in diagnosing TAPVC, accurately identifying abnormal pulmonary venous access [8,9]. Specifically, Xiang *et al*. [10] demonstrated that echocardiography provides high diagnostic accuracy for TAPVC and provides key anatomical information that is useful for preoperative planning. Its high-resolution and real-time imaging capabilities enable accurate assessment of cardiac structure and function, especially for diganosing complex congenital heart diseases such as TAPVC [11].

However, despite its advantages, comparative studies with computed tomography (CT) angiography (CTA) are relatively limited. Some studies have noted that while echocardiography is valuable in diagnosing congenital heart disease, in some cases, CT may provide additional, more comprehensive information [12]. For example, Chaosuwannakit *et al*. [13] highlighted the utility of cardiac CT in complex congenital heart disease, noting that CT provides more detailed anatomical information, which is critical for preoperative planning.

Therefore, this study aimed to systematically evaluate the feasibility of echocardiography combined with angiography in the diagnosis of abnormal locations of TAPVC. The aim was to provide more precise guidance for clinical decision-making and provide an important basis for formulating treatment plans and evaluating surgical effects for TAPVC.

# Methodology

## *Study Design*

This study is a retrospective cohort study to evaluate the clinical utility of echocardiography combined with angiography in the preoperative diagnosis of TAPVC in children. The study included all confirmed cases of TAPVC conducted at the Hunan Children's Hospital between February 2021 and February 2023, using a total of 105 cases. This study was approved by the Ethics Committee of Hunan Children's Hospital (HCHLL-2024-312). It is a retrospective study, with written informed consent from patients and families, in line with the Declaration of Helsinki, and all procedures followed were in accordance with institutional guidelines.

## *Study Subjects*

### Inclusion Criteria

(1) Age: 0–18 years old; (2) Diagnosed with TAPVC and surgically corrected; (3) Availability of preoperative and postoperative imaging examinations, including echocardiography and CTA; (4) Complete medical records, including preoperative echocardiogram reports and surgical records.

### Exclusion Criteria

(1) Presence of other severe congenital heart diseases that affects the diagnosis; (2) Previous cardiac surgery or interventional therapy; (3) Missing or incomplete imaging data.

## *Examination Methods*

### Echocardiography

Echocardiography used an EPIQ3.5C ultrasound machine (Philips, lot number: 20143234062, Amsterdam, Netherlands Netherlands) with a probe frequency of 7-7 MHz, and the patient was sedated before the examination. During the procedure, the patient is usually in the left decubitus position. Initially, two-dimensional (2D) imaging was used to obtain baseline images of the heart's structures, including pulmonary venous drainage pathways and structures of the atria and ventricles. Color Doppler imaging assessed the direction and velocity of pulmonary venous blood flow to identify abnormal blood flow patterns. Pulsed wave Doppler (PW Doppler) was used to measure blood flow velocity in the pulmonary veins to assess hemodynamic abnormalities. Data extracted from the echocardiogram report included the location of pulmonary venous drainage, structural abnormalities, and hemodynamic conditions.

### CTA Examination

A 64-slice spiral CT machine (Philips Brilliance, Netherlands) was used. All children were scanned under calm breathing in a sleeping state, and those who could not cooperate were given oral sedation with 10% chloral hydrate (Qingdao Yulong Seaweed Co., Ltd., Qingdao, China, H37022673) (0.5 mL/kg body weight) before the examination, and scanned in a calm breathing state after deep sleep. Scan parameters included a slice thickness of 1.0–1.5 mm, a scan interval of 1.0 mm, and coverage of the entire heart and major blood vessels. The tube current (mA) was typically regulated in the range of 50–100 mA, and the tube voltage (kV) was typically set between 80–120 kV. Iodine contrast agent (iodopamol injection, 350 mg/mL) (Shanghai Bolec Xinyi Pharmaceutical Co., Ltd., Shanghai, China, H20073014). Administered at a rate of 1.0–2.0 mL/s, 10–30 mL of normal saline was administered via a preelbow vein. The injection volume of iodinated contrast agent for children was calculated based on their body weight, with a single injection dose of 1.25 mL/kg. The maximum dose typically does not exceed 5 mL/kg of body weight or a total dose of 250 mL. Initial reconnaissance images were obtained to define the scan area and patient location, ensuring coverage of the entire heart and pulmonary veins. After the contrast agent was injected, a multiphase scan was performed to obtain dynamic images, and a variety of reconstruction algorithms were used to generate detailed three-dimensional images. The data extracted from the CTA report included the pulmonary venous drainage pathway and its relationship to the structure of the heart, including any abnormal drainage or other anatomical abnormalities.

Echocardiography and CTA were performed by professionals in our hospital's Department of Paediatric Imaging, who are consistently trained in the operation of imaging equipment and image acquisition and processing. The two radiologists read the film together, and if there was a disagreement, the decision was made through consultation or using the decision of the third radiologist.

### *Evaluation Indicators*

#### TAPVC Type

By observing the return path of the pulmonary veins, the type of TAPVC can be preliminarily determined [14], and according to the drainage route of the pulmonary veins, TAPVC can be divided into supracardiac, intracardiac, subcardiac, and mixed.

#### Evaluating the Combined Diagnostic Findings of Echocardiography and CTA

Echocardiography and CTA were evaluated separately for separate and combined diagnoses.

#### Auxiliary Diagnosis of Cardiac Malformations

TAPVC is often associated with other cardiac anomalies [15], such as atrial septal defect, ventricular septal defect, and patent ductus arteriosus. Echocardiography, CTA, and combined diagnosis were evaluated separately for diagnosing these cardiac malformations.

#### Preoperative Plan Assessment

A custom assessment scale was used to analyze the impact of echocardiography and CTA on surgical planning. The scale consists of three sections: image clarity (5 items), anatomical representation (4 items), and support for surgical planning (4 items), and the total score for each part was calculated and compared. The content validity (S-CVI) of this scale was 0.892, and the test-retest reliability was 0.834.

### *Statistical Analysis*

Data analysis was performed using SPSS 26.0 (SPSS Inc., Armonk, NY, USA). Descriptive statistics were used for basic information (age, gender, weight, etc.), continuous variables were reported as mean ± standard deviation (SD), after applying the paired *t*-test; categorical variables were reported as n, %. McNemar's Chi-square and Fisher exact probabilities were applied to assess the differences between the three methods of echocardiography, CTA, and combined diagnosis. The confidence level was 95% and two-sided test statistics were deemed significant when $p < 0.05$.

**Table 1. Demographic characteristics (Mean ± SD) (n, %).**

| Index | |
|---|---|
| Age (days) | 8.52 ± 3.24 |
| Gender | |
| Male | 58 (55.24%) |
| Female | 47 (44.76%) |
| Body weight (kg) | 3.24 ± 0.52 |
| Height (cm) | 65.82 ± 6.71 |
| Heart rate (beats/min) | 137.09 ± 11.29 |
| Birth status | |
| Premature | 22 (20.95%) |
| Term infant | 83 (79.05%) |

## Results

### *Clinical Data*

The basic information collected from the hospital's medical record system includes age, gender, weight, height, birth weight, and birth details. A total of 105 pediatric patients with TAPVC scheduled for corrective surgery were included in this study. Table 1 summarizes the demographic characteristics of the children.

### *TAPVC Type Diagnosis*

The results of Table 2 show that the positive diagnosis rate of TAPVC after combined echocardiography and CTA was 100%, of which 46 cases were supracardiac type, 33 cases were intracardiac, 14 cases were subcardiac type, and 12 cases were mixed type. The diagnostic rate of echocardiography was 82.86%, which was lower than that of CTA (94.29%). Among the three diagnostic methods, the combined diagnosis method had the highest diagnosis rate and was statistically significant ($p < 0.05$).

### *Diagnosis of Related Cardiac Anomalies*

Table 3 provides detailed information on the diagnosis of cardiac malformations associated with paediatric TAPVC. The correct recognition rate of echocardiography in the diagnosis of related malformations (91.43%) was lower than that of CTA (97.14%), and the correct recognition rate of combined diagnosis was 100%, which was statistically significant ($p < 0.05$), as detailed in Table 3.

### *Comparison of the Details of the Two Methods for Diagnosing TAPVC*

Two independent cardiologists evaluated the imaging approach based on the clarity of the images, the level of detail, and their support for the surgical plan. Table 4 compares the details provided by echocardiography and CTA for preoperative planning. The results showed that CTAs were superior in terms of image clarity ($p < 0.001$). How-

**Table 2. Diagnostic accuracy of cardiac classification by different diagnostic modalities (n, %).**

| Diagnostic methods | Diagnostic results | Superior cardio (n = 46) | Intracardiac (n = 33) | Subcardiac (n = 14) | Hybrid (n = 12) | Total (n = 105) |
|---|---|---|---|---|---|---|
| Echocardiography | Diagnosed | 40 (86.96%) | 28 (84.85%) | 10 (71.43%) | 9 (75.00%) | 87 (82.86%) |
| | Missed diagnosis/misdiagnosis | 6 (13.04%) | 5 (15.15%) | 4 (28.57%) | 3 (25.00%) | 18 (17.14%) |
| CTA | Diagnosed | 45 (97.83%) | 32 (96.97%) | 13 (92.86%) | 10 (83.33%) | 99 (94.29%) |
| | Missed diagnosis/misdiagnosis | 1 (2.17%) | 1 (3.03%) | 1 (7.14%) | 2 (16.67%) | 6 (5.71%) |
| Joint diagnosis | Diagnosed | 46 (100.00%) | 33 (100.00%) | 14 (100.00%) | 12 (100.00%) | 105 (100.00%) |
| | Missed diagnosis/misdiagnosis | 0 (0.00%) | 0 (0.00%) | 0 (0.00%) | 0 (0.00%) | 0 (0.00%) |
| $x^2$ | | 9.330 | 7.451 | 5.902 | 3.251 | 22.732 |
| *p* value | | 0.003* | 0.024* | 0.052 | 0.196 | <0.001* |

NOTE: * indicates that $p < 0.05$ between the three groups. CTA, computed tomography angiography.

**Table 3. Diagnosis of related cardiac malformations (n, %).**

| Diagnostic methods | Diagnostic results | Atrial septal defect (n = 81) | Ventricular septal defect (n = 11) | Patent ductus arteriosus (n = 13) | Total (n = 105) |
|---|---|---|---|---|---|
| Echocardiography | Correct misidentification | 78 (96.30%) | 8 (72.73%) | 10 (76.92%) | 96 (91.43%) |
| | | 3 (3.70%) | 3 (27.27%) | 3 (23.08%) | 9 (8.57%) |
| CTA | Correct misidentification | 80 (98.77%) | 10 (90.91%) | 12 (92.31%) | 102 (97.14%) |
| | | 1 (1.23%) | 1 (9.09%) | 1 (7.69%) | 3 (2.86%) |
| Joint diagnosis | Correct misidentification | 81 (100.00%) | 11 (100.00%) | 13 (100.00%) | 105 (100.00%) |
| | | 0 (0.00%) | 0 (0.00%) | 0 (0.00%) | 0 (0.00%) |
| $x^2$ | | 3.558 | 3.982 | 3.900 | 6.391 |
| *p* value | | 0.168 | 0.136 | 0.142 | 0.040* |

NOTE: * mean difference of <0.05 between the three groups.

ever, echocardiography provided better anatomical detail than CTA ($p = 0.011$). There was no statistically significant difference between the two methods in supporting surgical planning ($p > 0.05$).

### *Typical Imagery*

See the Fig. 1 and Fig. 2.

## Discussion

In this study, we evaluated the clinical utility of echocardiography and CTA in TAPVC and compared the two diagnostic methods alone with a combined applied diagnosis. Our results show that both echocardiography and CTA exhibit high accuracy in the combined diagnosis of TAPVC.

First, in terms of the consistency of TAPVC type diagnosis, the overall accuracy of echocardiography reached 82.86%, CTA reached 94.29%, but the overall accuracy of combined diagnosis was 100%. Although echocardiography was able to identify the TAPVC classification in most cases, there were still a few cases of missed diagnosis and misdiagnosis. Particularly in complex classifications such as mixed TAPVC, these misdiagnoses on echocardiography may be related to image processing, scan angles, and anatomical changes, and the anatomical details may be inadequately resolved [16]. In contrast, CTA, with their high-resolution and three-dimensional imaging capabilities, can identify complex anomalies more accurately. This is consistent with the findings of Oh *et al.* [17] and Jiang *et al.* [18], who highlighted the advantages of echocardiography in the diagnosis of TAPVC types, but also pointed out its limitations in the presentation of anatomical details.

Regarding the diagnosis of heart-related malformations, the correct recognition rate of echocardiography for diagnosing related malformations (91.43%) was lower than that of CTA (97.14%), and the correct recognition rate of combined diagnosis was 100%. This may be due to an atrial septal defect that had been incorrectly diagnosed as an atrial septal defect with a ventricular septal defect on echocardiography. This misdiagnosis occurred because echocardiography failed to clearly distinguish the anatomy of an atrial septal defect from a ventricular septal defect, resulting in confusion between the two types of defects in the image. However, echocardiography has shown a unique advantage in the identification of cardiac-associated malformations, as it can identify subtle malformations in the detailed anatomy of the heart and large vessels and provide good clinical applicability [19]. For example, echocar-

**Table 4. Comparison of the details of the two methods for diagnosing TAPVC (Mean ± SD, Score).**

| Aspect | Echocardiography | CTA | t | $p$ |
|---|---|---|---|---|
| Image clarity | | | | |
| Image resolution | 3.78 ± 0.83 | 4.49 ± 0.72 | 6.621 | <0.001 |
| Image contrast | 4.04 ± 0.63 | 4.69 ± 0.59 | 7.717 | <0.001 |
| Image stabilization | 3.70 ± 0.68 | 4.53 ± 0.80 | 8.100 | <0.001 |
| Image acquisition timing | 4.10 ± 0.67 | 4.42 ± 0.78 | 3.189 | 0.002 |
| Image noise | 3.90 ± 0.93 | 4.60 ± 0.80 | 5.847 | <0.001 |
| Score | 19.52 ± 2.96 | 22.72 ± 2.21 | 8.877 | <0.001 |
| Introduction to anatomy | | | | |
| Pulmonary vein location | 4.02 ± 0.52 | 4.32 ± 0.56 | 4.023 | <0.001 |
| Blood flow in the atrium | 4.27 ± 0.44 | 4.01 ± 0.66 | 3.359 | 0.001 |
| Abnormal drainage | 4.46 ± 0.67 | 4.23 ± 0.71 | 2.414 | 0.017 |
| Other relevant anatomical structures | 4.29 ± 0.59 | 3.78 ± 0.64 | 6.004 | <0.001 |
| Score | 17.04 ± 2.05 | 16.34 ± 1.92 | 2.554 | 0.011 |
| Surgical planning support | | | | |
| Feasibility of surgical planning | 4.23 ± 0.55 | 4.12 ± 0.42 | 1.629 | 0.105 |
| Preoperative planning details | 4.45 ± 0.47 | 4.23 ± 0.53 | 3.182 | 0.002 |
| Surgical risk assessment | 4.26 ± 0.48 | 4.32 ± 0.50 | 0.887 | 0.376 |
| Postoperative outcome prediction | 4.13 ± 0.64 | 4.09 ± 0.62 | 0.460 | 0.646 |
| Score | 17.07 ± 1.82 | 16.76 ± 1.87 | 1.689 | 0.093 |

NOTE: * indicates that $p < 0.05$ between the two groups. TAPVC, total anomalous pulmonary venous connection.

diography can provide comprehensive information through multi-view and dynamic observation when evaluating minor anatomical abnormalities such as atrial septal defects and ventricular septal defects. These advantages are essential to guide preoperative decision-making and surgical planning. CTA, on the other hand, makes it easier to visualize the external structures of the heart and large vessel malformations. By applying these two tests together, a comprehensive assessment of the internal and external structures of the heart can be achieved, further improving the diagnostic accuracy of heart-related malformations. The study by Keller *et al.* [20] and Lancellotti *et al.* [21] also noted that while CTA excels in structural analysis, the advantages of echocardiography in functional assessment and ambulatory monitoring make it irreplaceable in a real-world setting.

The results of the preoperative planning showed that CTA was significantly superior to echocardiography in terms of image clarity ($p < 0.001$), but inferior to echocardiography in the presentation of anatomical structures ($p = 0.011$). However, there was no statistically significant difference between the two methods in supporting surgical planning ($p > 0.05$). This finding warrants further exploration to understand the role and limitations of these two modalities in preoperative planning. The advantage of CTA in terms of image clarity lies in its high resolution and better contrast, which allows for a clearer depiction of detailed cardiac and macrovascular structures, especially under high-resolution and low-noise conditions [22]. These features provide critical visual information for the management of complex cardiac disease and preoperative planning, consistent with the available literature [23,24]. Despite the superior image quality of CTA, echocardiography did not show a significant difference in support of preoperative planning compared to CTA ($p > 0.05$). This result suggests that other factors may influence the support provided in each modality in the preoperative program. First, while echocardiography has a lower image resolution than CTA, its real-time imaging advantages allow for dynamic assessment and monitoring prior to surgery. This real-time assessment is essential for understanding cardiac function and subtle structural changes, providing additional functional information that is critical for complex case evaluation. Second, the non-invasive and convenient nature of echocardiography makes it valuable in clinical practice. For pediatric patients, point-of-care echocardiography reduces the need for patient transfer and minimizes surgical complexity and risk. Real-time feedback also helps doctors adjust surgical plans immediately, potentially mitigating the effects of lower image resolution. This dynamic assessment capability complements the high-resolution imaging of CTAs to provide comprehensive preoperative evaluation support.

## Limitations

While this study provides comparative data on echocardiography (Fig. 1) and CTA (Fig. 2), for preoperative planning of pediatric TAPVC cases , there are some limitations. First, the data are derived from a single center with a relatively small sample size, which may affect the external validity and generalizability of the results. Mul-

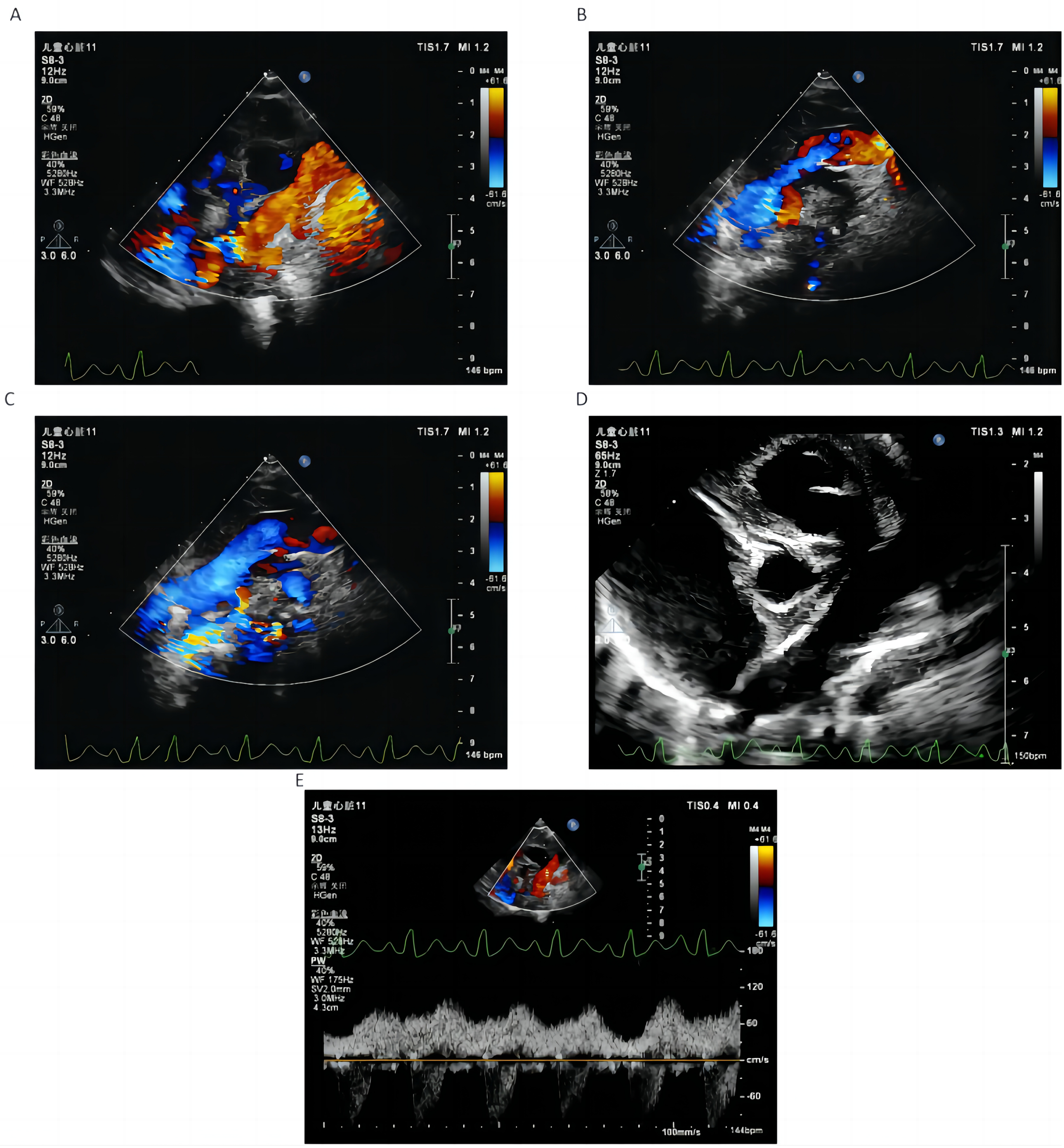


**Fig. 1. Echocardiographic imaging of pulmonary vein abnormalities.** (A) Complete supracardiac pulmonary vein abnormality – color Doppler image showing a vertical vein. (B) Complete supracardiac pulmonary vein abnormality – color Doppler image showing vertical vein flexion towards the right atrium. (C) Complete supracardiac pulmonary vein abnormality – color Doppler image of vertical venous drainage to the right atrium. (D) Complete supracardiac pulmonary vein abnormalities—two-dimensional echocardiographic images of vertical veins. (E) Complete supracardiac pulmonary vein abnormality—pulsed wave Doppler spectrum of the veins in the vertical direction.

ticenter, large-scale studies can provide a wider range of validation to improve the reliability and applicability of research results. Second, the quality of echocardiogram and CTA images is affected by a variety of factors. Although we systematically compared these two modes, the present study did not control for all potential image quality differences, nor did it explore the potential radiation hazards that contrast agents may pose to pediatric patients. In addition, the study did not analyze in detail the specific advantages of echocardiography in terms of dynamic assessment and real-

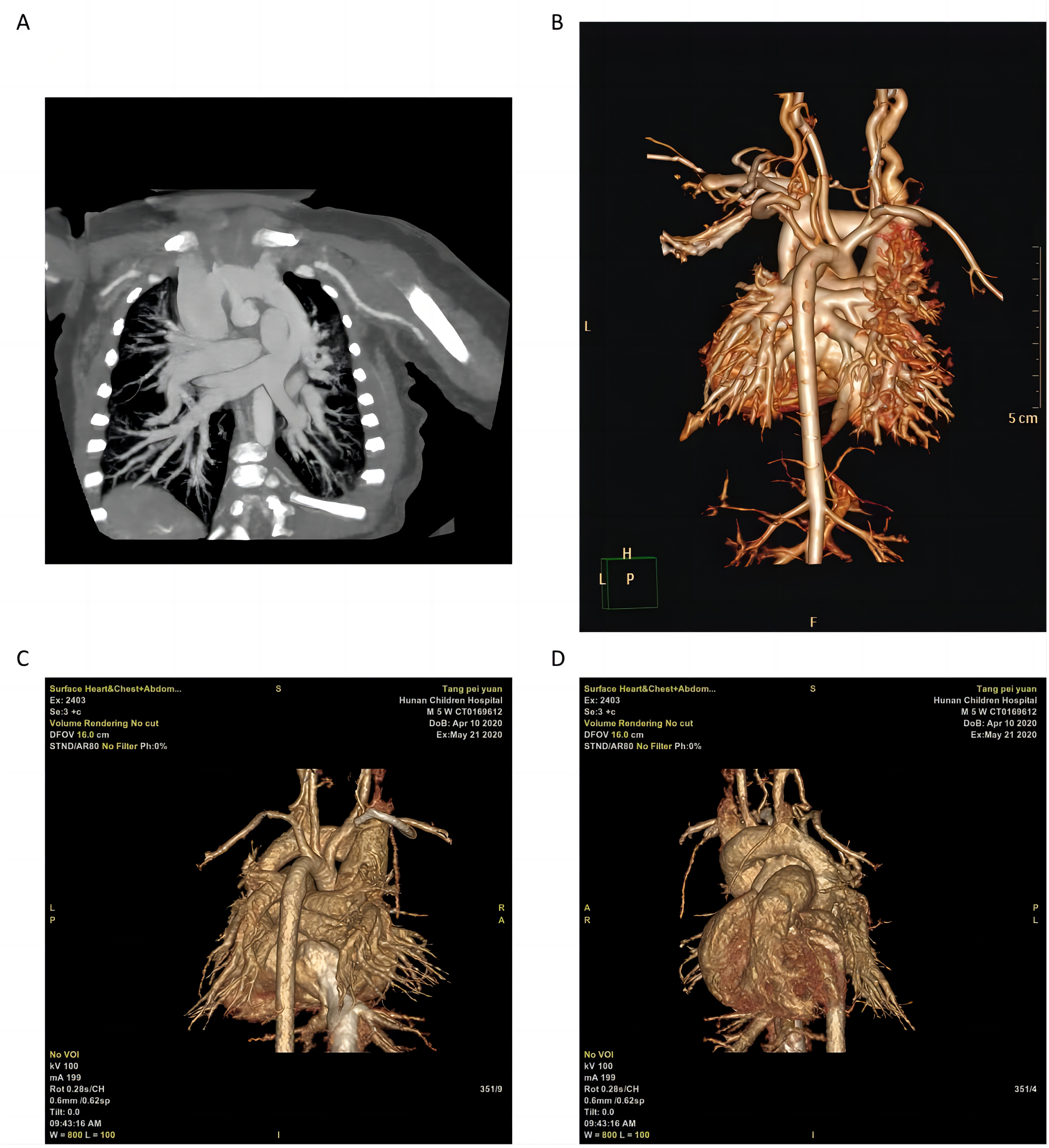


**Fig. 2. Detailed CTA 3D reconstruction of pulmonary veins.** (A) The Maximum Intensity Projection (MIP) demonstrates the confluence of the four pulmonary veins, which subsequently drain into the brachiocephalic veins via vertical veins, and then return to the right atrium through the dilated superior vena cava. (B) The Volume Rendering (VR) image reveals the convergence of the four pulmonary veins into a common lumen. (C) VR image displays the aortic arch and its branches, as well as the left and right pulmonary arteries, with the inferior right pulmonary vein also visible. (D) VR image shows the pulmonary artery outlet, aortic arch, and its branches. 3D, three dimensiona.

time monitoring, nor did it assess performance differences across different operator or equipment conditions. Future studies could explore the following: Conduct multicenter, large-scale prospective studies and develop a detailed study protocol to verify the generalizability of the results. Evaluate the performance of echocardiography and CTA in different clinical settings. Expand the sample size and diversify the study population to provide a more complete picture of the role and benefits of each modality in preoperative planning. Multimodal imaging-based fusion techniques may provide more comprehensive anatomical and functional information to help optimize preoperative planning and postoperative evaluation. Further research should also focus on the potential of echocardiography in dynamic assessment, particularly for real-time monitoring and microstructural analysis. Exploring the impact of different imaging devices and operating techniques on outcomes can help develop more precise imaging assessment strategies and improve the accuracy of preoperative planning.

## Conclusions

This study shows that while CTA with echocardiography performs well in diagnosing TAPVC types and associated cardiac malformations, the combined application of echocardiography and CTA can mutually validate the diagnostic results and reduce the possibility of misdiagnosis and missed diagnosis. The combination of the two imaging techniques can provide more comprehensive preoperative information and potentially improve surgical outcomes.

## Availability of Data and Materials

The datasets used and/or analysed during the current study were available from the corresponding author on reasonable request.

## Author Contributions

YP and YH designed the study; all authors conducted the study; LL, YX, JL and QL collected and analyzed the data. YX and JL participated in drafting the manuscript, and all authors contributed to critical revision of the manuscript for important intellectual content. All authors gave final approval of the version to be published. All authors participated fully in the work, take public responsibility for appropriate portions of the content, and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or completeness of any part of the work are appropriately investigated and resolved.

## Ethics Approval and Consent to Participate

This study was approved by the Ethics Committee of Department of Hunan Children's Hospital, Changsha Hospital (institution review board number, HCHLL-2024-312) and was performed in accordance with the principles of the Declaration of Helsinki. Informed consent of both patient and guardian.


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## Conflict of Interest

The authors declare no conflict of interest.

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