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Original article

The Role of Dual-Source Multi Slice Computed Tomography in Preoperative Assessment of Anomalous Pulmonary Venous Connection Cases Compared to Echocardiography

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Abstract:

Background: Background: The pulmonary veins can be attached to the right atrium in a variety of ways, including direct connections or systemic venous returns; this condition is known as an anomalous congenital connection of the pulmonary veins. This study aimed to assess the diagnostic agreement and image quality of dual-source computed tomography (DSCT) for anomalous pulmonary venous connection (APVC) prior to surgery in comparison to transthoracic echocardiography (TTE). **Methods:** This prospective study included 50 consecutive patients diagnosed with congenital complex cardiac malformations who were referred for a cardiac and extra-cardiac anomalies workup using computed tomography (CT) angiography in the Department of Radio-diagnosis at Benha University Hospital and Al-Nas Hospital for Children. All angiograms were performed using multi-detector CT (MDCT). **Results:** Kappa statistics revealed good significant agreement between multislice CT (MSCT) and echocardiography (ECHO) in the preoperative assessment of ostium secundum atrial septal defect (ASD) (kappa = 0.745, 95% CI = 0.555 to 0.936, $p < 0.001$). There was excellent significant agreement between MSCT and ECHO in the preoperative assessment of sinus venosus ASD (kappa = 1.00, $p < 0.001$). DSCT provided superior anatomical detail for pulmonary vein morphology, drainage sites, and obstruction. Partial anomalous pulmonary venous return (PAPVR) cases were more frequent than total anomalous pulmonary venous connection (TAPVC) cases, and the supracardiac subtype was the most common. **Conclusions:** Dual-source computed tomography (DSCT) is a reliable tool for the preoperative assessment of APVC. It showed excellent agreement with TTE in detecting ostium secundum ASD and sinus venosus ASD. DSCT provided superior anatomical visualization compared to TTE, especially regarding pulmonary vein morphology, drainage patterns, and venous obstructions.

Keywords: Dual-Source Computed Tomography (DSCT); Preoperative Assessment; Anomalous Pulmonary Venous

Introduction

Any one of several disorders characterized by a direct or indirect fusion of the pulmonary veins with the right atrium (RA)—also known as "anomalous congenital connections of the pulmonary veins"—fall under this umbrella term [1].

A total anomalous pulmonary venous connection (TAPVC) is present when all veins in the body connect abnormally, "while partial anomalous pulmonary venous connection (PAPVC) is present when some veins connect abnormally but not others." [2].

While echocardiography (ECHO) and catheter angiography are typically used to assess anomalous pulmonary venous return (APVR). Low dose multidetector computed tomographic angiography (MDCTA) and magnetic resonance imaging (MRI) are now more important in the diagnosis of these abnormalities [3].

Common signs of APVC include difficulty breathing, reduced exercise tolerance, and eventually circulatory collapse [4]. The sole option for stopping the disease from getting worse is surgery, but because it is so complex, there have been reports of high operative mortality rates [5]. Consequently, minimization of surgical risk requires an appropriate imaging modality to enhance preoperative planning [6].

The most reliable method of diagnosing congenital heart disease through imaging has traditionally been cardiac catheterization [7]. High radiation doses and the risks associated with anesthesia make it a questionable choice [5]. Additionally, in APVC, iatrogenic venous blockage as a result of catheter-related injuries must be considered. The diagnostic accuracy of trans-thoracic echocardiography (TTE) relies heavily on the operator's skill set, the size and quality of the acoustic window, and the patient's APVC severity [8].

Despite the lack of radiation exposure, resonance imaging can be prohibitively expensive, requires sedation, and takes a long time to complete the examination [9].

The dual-source computed tomography (DSCT) system has been widely used in the diagnosis and treatment of complex congenital heart diseases due to its numerous advantageous features, such as a significant decrease in radiation dose, superior picture quality, strong image postprocessing, and high spatial and temporal resolution [10].

The purpose of this study was to compare DSCT and TTE in terms of image features and diagnostic agreement for APVC prior to surgery.

Methods

This prospective study included 50 consecutive patients diagnosed with congenital complex cardiac malformations on clinical who were referred to do CT cardiac angiogram for cardiac and extra-cardiac anomalies work up in the department of radio-diagnosis at Benha University Hospital and AL-Nas Hospital for children from April 2023 to November 2024 .An informed written consent was obtained from the patients. Every patient received an explanation of the purpose of the study and had a secret code number. The study was done after being approved by the Research Ethics Committee, Faculty of Medicine, Benha University Hospital and AL-Nas Hospital for children.

Inclusion criteria were All patients with known congenital cardiac anomalies (total and partial anomalous pulmonary venous connection) were evaluated for preoperative congenital heart disease (CHD) using echocardiography. There was no preference based on gender. Patients' ages ranged from 0 to 61 years old.

Exclusion criteria were individuals with a history of hypersensitivity to iodinated contrast medium reactions, patients with impaired renal function (Creatinine> 2 mg/dl), patients without prior ECHO studies, patients experiencing fever, severe asthma, or arrhythmia, and parents who, after being informed of the benefits and

risks of CT angiography, were unwilling to subject their child to radiation.

The procedure was explained in detail to the parents or patients, possible side effects of the contrast medium injection and radiation exposure were discussed, informed consent was obtained, a complete medical history was taken, vital signs and anthropometric measurements were taken, renal function tests (blood urea and serum creatinine) were administered, the patients were fasted for four to six hours, and a peripheral venous line was placed in the foot's vein. For neonates and uncooperative children under the supervision of a paediatrician, 45 cases involved administering IV ketamine at a dose of 0.5-1 mg/kg of body weight, or oral chloral hydrate at a dose of 0.5 ml/kg of body weight. In 5 cases, the patient was able to follow the technician's instructions without sedation. After contrast was administered, we experienced two cases of mild hypersensitivity reactions.

Technique and CT imaging:

All the angiograms were performed using multi detector CT (MDCT) (15 cases were done by GE 128 slice CT scan and 35 cases were done by Siemens somatom drive 128 dual source machines). All of the people were lying down on their backs. The patient underwent a cranio-caudal scan after electrocardiogram leads were applied to their chest. Beginning at the base of the skull and continuing inferiorly to the level of the portal vein, this scan encompasses the proximal common carotid and subclavian arteries. This scan is crucial for identifying an abnormal pulmonary venous drainage of the infra-diaphragmatic type. Except for 10 cases where arrhythmia made retrospective gating more convenient, all other cases underwent prospective ECG gating using a low dose protocol.

The quantitative characteristics of APVC, such as the dimensions of the cardiac chambers and the vertical vein, as well as the morphological features, such as the course of each pulmonary vein and any related intra- and extracardiac abnormalities, were recorded and shown for DSCT. Cardiac chamber dimensions were measured in the same planes as TTE using computer callipers.

An experienced cardiologist measured and mapped all veins and any abnormalities that may be present in order to conduct TTE. The apical four-chamber view and the parasternal left ventricular long-axis view were used to measure the left atrium (LA) and right atrium (RA), respectively, at the end of systole. Nevertheless, diastole was the last point at which the LV and RV were measured. When the peak velocity was more than 1.3 m/s, the pulmonary veins were thought to be blocked according to Doppler color flow imaging. Supracardiac, cardiac, infracardiac, and mixed veins are the four main types of pulmonary veins. We calculated the diagnostic agreement between DSCT and TTE and identified the drainage site and origin for each pulmonary vein.

If the doctor failed to notice any abnormal pulmonary veins in a patient or illustrated the incorrect drainage site, it was deemed a missed anomaly. The surgical findings served as the gold standard in confirming the results.

Contrast material administration: The patient was injected with 1.5-2ml/kg of Omnipaque 300 mg/ml (Iohexol, GE Health Care Ireland, Cork, Ireland), a non-diluted non-ionic contrast material, into a peripheral foot vein at a rate of 1.5 ml/sec. Injections of up to 20 ml were performed manually using sterile syringes. We used a manual bolus-tracking technique to get pictures; we positioned the monitoring section over the heart's four chambers and the ROI outside the chest. Once the contrast medium opacification was achieved in both the right and left hearts and the artifact in RA started to disappear, the acquisition was manually triggered.

Scan parameters: While conducting cardiac CT scanning, we adhered to the following parameters: a kilo volt (KV) range of 80-100 kilovolts (MA), a gantry

speed of 0.35 seconds (rpm), a helical thickness of 0.2-0.4 mm, and a multi-phase examination of the heart in the mid-venous and mid-arterial phases of enhancement to guarantee opacification of all chambers and extra-cardiac vessels. Following the procedure, the patient was observed for 15-30 minutes until they recovered from the sedation, in order to achieve good homogeneous opacification of the systemic and pulmonary circulations.

Image reconstruction and post processing:

To make sure the axial images were of good quality, they were quickly reviewed after being reconstructed at a slice thickness of 0.6 mm. The data was subsequently imported into the post-processing software Vitrea workstation version 5.2 (Toshiba) and syngo.via (Siemens). Image quality of magnetic resonance angiography (MPR) was better in depicting both full and partial anomalous venous drainage as well as vertical vein drainage into systemic veins. Through the use of three-dimensional reconstruction, the diameter of the vertical vein was determined at the level of the ipsilateral pulmonary artery. Obstruction of abnormal pulmonary veins was defined as a reduction of 50% or more from the largest measured area of the pulmonary vein or draining vein, or a connection between the draining vein and the portal vein.

Approval code: MD 13-3-2023

Statistical analysis

In order to analyze the data that was input into the computer, we utilized IBM SPSS software package version 25.0 (IBM Corp. Released 2017). IBM SPSS Statistics for Windows, Version 25.0, Armonk, New York, USA: IBM Corp. For both quantitative and qualitative data, counts and percentages were used to describe the information. The Shapiro-Wilk test was used to verify if the distribution was normal. Quantitative data was described using measures such as mean, standard deviation, median, and range (both minimum and maximum). The results were approved as statistically significant at the 5% level. With the use of the Kappa statistic, we assessed how well the echo and CT results agreed with one another. According to some sources that discuss the Kappa statistic, a kappa value of 1 indicates perfect agreement, while a kappa value greater than 0.8 indicates exceptional agreement. Low agreement is indicated by a kappa value below 0.4, whereas moderate to excellent agreement is indicated by a kappa value between 0.41 and 0.8. We used the McNemar test to look for differences between the echo and CT scan findings. We refrained from performing any statistical experiments that were biased. We regarded as statistically significant any p-values that were lower than 0.05.

Cases presentation:

Case 1: Clinical data: A female patient two months old presented with recurrent chest infection, tachycardia& cyanosis. ECHO findings: Common AV canal. CT diagnosis: Supra-cardiac TAPVR, MAPCAS, common AV canal, heterotaxy syndrome (right isomerism). **Figure 1**

Case 2: Clinical data: A male patient 1month old presented with recurrent chest infection &tachycardia. ECHO findings: Hypoplastic right pulmonary artery (RPA). CT diagnosis: Scimitar syndrome (PAPVR, infra-cardiac type), hypoplastic right lung, hypoplastic RPA, right lower lung lobe sequestration and Bochdalek hernia. **Figure 2**

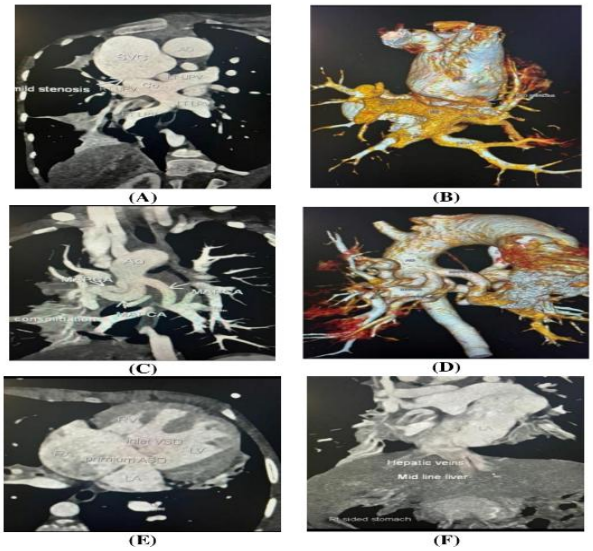

Figure 1:MSCT showing: A&B: axial oblique and VR images show: all right and left pulmonary veins are seen draining into common confluence that show mild stenosis at its entry in the superior vena cava (TAPVC, supracardiac type). C&D: coronal MIP and VR images show: major aortopulmonary collateral arteries (MAPCAs) arising from the ascending aorta supplying the lung. E: Axial 4 chamber view shows premium ASD and inlet VSD, complete atrioventricular canal (CAVC). F: coronal MIP images *show: midline liver and* right sided stomach (right isomerism).

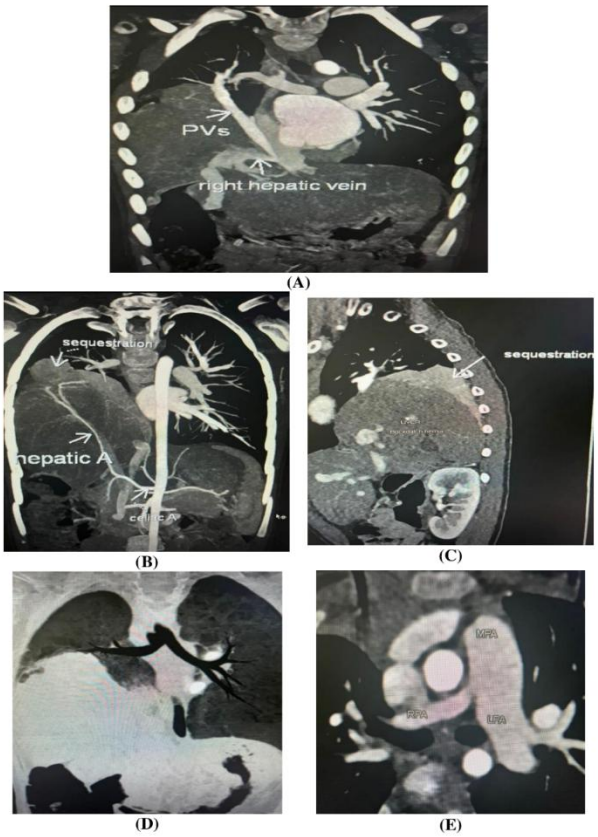

Figure 2:MSCT showing: A: coronal MIP images show: the right pulmonary veins are seen draining into the right hepatic vein via descending vertical vein (PAPVC, infracardiac type) B&C: coronal oblique and sagittal MIP images show large right sided Bochdalek hernia with liver herniating into the right hemithorax& seen inseparable from right lower lung lobe consolidation(sequestration) with arterial supply from hepatic artery. D: coronal Minip images show hypoplastic right lung with non-visualized right lower bronchus. E: axial oblique images show: hypoplastic right pulmonary artery

Results

Based on the data provided for studied patients, the age of patients ranged between 0.05 to 61 years with a mean age of 6.72± 13.68 years and median 0.87 years. Most patients (90%) were less than 18 years. More than half patients (54%) were females and 46% cases were males with male to female ratio was 0.852. Regarding onset of disease, most cases (64%) had gradual onset and 36% of them had sudden onset. The weight of patients ranged between 3.1 Kg to 108 Kg with a mean weight of 19.5± 23.49 Kg and median 9.9 Kg. Regarding type of anomalies, the most common pulmonary venous anomaly encountered in this study was PAPVR with its four subtypes representing 62% of the cases. Supracardiac type was the commonest subtype accounting for 20% of TAPVR cases while supracardiac type occurred in 52% of PAPVR cases. SVC was the most common site of drainage (50%) followed by innominate vein (22%). Other sites were; Innominate vein & coronary (6%), RA (6%), SVC & RT atrium (mixed type) (8%), coronary sinus (4%) and Inferior vena cava (IVC) (4%). Out of 50 patients, 20 cases (40%) reported presence of vertical veins, three cases of them had obstructed vertical veins while 17 cases had non-obstructed vertical veins **Table 1**

Table 1: Demographic data, clinical data, distribution of the studied patients as per type of anomalies, site of drainage and vertical veins among the studied patients

Description			Studied patients(N= 50)	
			N	%
Demographic data	**Gender**	**Male**	23	46.0%
		Female	27	54.0%
	Age group	**< 18 years**	45	90.0%
		18 years- 60 years	3	6.0%
		> 60 years	2	4.0%
	Age (years)	**Mean± SD**	6.72± 13.68	
		Median (Range)	0.87 (0.05 – 61)	
Clinical data	**Onset**	**Gradual**	32	64.0%
		Sudden	18	36.0%
	Weight (Kg)	**Mean± SD**	19.5± 23.49	
		Median (Range)	9.9 (3.1 – 108)	
Type of anomalies	**Total anomalous**		19	38.0%
	Supra-cardiac		10	20.0%
	Cardiac		3	6.0%
	Infra-cardiac		1	2.0%
	Mixed		5	10.0%
	Partial anomalous		31	62.0%
	Supra-cardiac		26	52.0%
	Cardiac		2	4.0%
	Infra-cardiac		1	2.0%
	Mixed		2	4.0%
Site of drainage	**SVC**		25	50.0%
	Innominate vein		11	22.0%
	Innominate vein & coronary sinus		3	6.0%
	SVC & RT atrium		4	8.0%
	Right atrium		3	6.0%
	IVC		2	4.0%
	Dilated coronary sinus		2	4.0%
Vertical veins	**Present**		20	40.0%
	Obstructed		3	6.0%

Data presents as mean ± SD or frequency (%). SD: standard deviation, SVC: Superior vena cava, IVC: Inferior vena cava.

All patients included in this study were examined by CT & ECHO. Regarding CT, ostium secondum atrial septal defect (ASD) was found in 19 (38%) of patients and 29 (58%) of cases had sinus venosus ASD while 2 cases were not associated with sinus venous ASD. While in ECHO, 19 (38%) of cases had ostium secondum ASD and 29 (58%) of cases had sinus venosus ASD while 2 cases were not associated with sinus venous ASD. McNemar test was used to show the difference between CT and ECHO findings. The results showed non-significant difference between the two modalities according to Ostium secondum ASD and Sinus venosus ASD. **Table 2**

Kappa statistics revealed good significant agreement between multislice CT (MSCT) and ECHO in preoperative assessment of ostium secondum ASD (kappa=0.745, 95%CI= 0.555 to 0.936, p<0.001). Kappa statistics revealed excellent significant agreement between MSCT and ECHO in preoperative assessment of sinus venosus (kappa=1.00, p<0.001). **Table 3**

There was significant relation between dual-source MSCT and ECHO in preoperative assessment of anomalous pulmonary venous connection (p=0.003) as they were detected by ECHO in 40 (80%) cases. The other 10 cases were confirmed by CT while those cases were missed by ECHO. **Table 4**

Table 2: Comparison between CT and Echocardiography findings among the studied patients

	CT findings		**Echocardiography findings**		**P-value#**
	N	**%**	**N**	**%**	
Ostium secondum ASD	19	38.0%	19	38.0%	>0.999
Sinus venosus ASD	29	58.0%	29	58.0%	>0.999
Not associated with sinus venous ASD	2	4.0%	2	4.0%	>0.999

Data presents as frequency (%). P value >0.05: Not significant, *P value <0.05 is significant, **p<0.01 is highly significant. ASD: Atrial septal defect, CT: computed tomography. # McNemar test

Table 3: Agreement between CT and echocardiography in preoperative assessment of ostium secondum ASD and preoperative assessment of sinus venosus ASD

			Echocardiography						
			Negative		**Positive**		**Total**	**Kappa (95%CI)**	***P*-value**
			No.	**%**	**No.**	**%**			
Ostium secondum ASD	**CT**	**Negative**	28	52%	3	6%	31	0.745 (0.555 to 0.936)	**<0.001***
		Positive	3	6%	16	32%	19		
	Total		31	58%	19	38%	50		
Sinus venosus ASD	**CT**	**Negative**	19	38%	0	0.0%	19	1.0 (1.0 to 1.0)	**<0.001***
		Positive	0	0.0%	29	58.0%	29		
	Total		19	38%	29	58.0%	48		

Data presents as mean ± SD or frequency (%). ASD: Atrial septal defect, CT: computed tomography. *: significant as P value ≤ 0.05

Table 4: Relation between dual-source multislice computed tomography in preoperative assessment of anomalous pulmonary venous connection cases compared to echocardiography

	CT findings		**Echocardiography findings**		**P-value#**
	N	**%**	**N**	**%**	
Diagnosed	50	100.0%	40	80.0%	**0.003****
Missed	0	0.0%	10	20.0%	

Data presents as frequency (%). CT: computed tomography. P value >0.05: Not significant, *P value <0.05 is significant, **p<0.01 is highly significant.

Discussion

At 4-10 per 1,000 live births, congenital heart defects (CHDs) are the most common type of congenital anomaly. Nearly 90% of coronary heart disease (CHD) patients now live to adulthood, thanks to vast improvements in patient survival rates brought about by developments in diagnostic tools and surgical management in the last several decades. Accurate preoperative diagnosis is crucial for complex congenital heart defects (CHD) cases, which frequently exhibit multiple malformations. Coronary artery disease (CAD) diagnostic options include echocardiography (ECHO), magnetic resonance imaging (MRI), and computed tomography (CT), all of which have their own set of benefits and drawbacks [11].

The median age of 0.87 years reflects a significant proportion of very young patients, likely attributed to early disease onset or screening practices in this age group. The slightly higher prevalence of females (54%) compared to males (46%), with a male-to-female ratio of 0.852:1, may suggest potential gender-related factors influencing disease prevalence or healthcare-seeking behavior.

On the contrary, Li et al. [12] patients underwent primary sutureless TAPVC repair, a study was conducted. Out of the 80 patients, 47 were male (58.8%) and 33 were female (41.2%).

This difference may reflect variations in the study populations, geographic regions, or other demographic factors that influence the prevalence of TAPVC. Additionally, the focus on a specific surgical intervention in Li et al. [12] study could introduce selection bias, potentially skewing the gender distribution compared to a broader population.

PAPVR emerged as the most frequent pulmonary venous anomaly in this study, accounting for 62% of cases and highlighting its relative predominance in congenital pulmonary venous abnormalities.

Confirming our study, Broy and Bennett et al. [13] reported a soldier who had just been activated, who had dyspnea upon exertion that did not respond to inhaled corticosteroids, and who had an incidental 8.5-mm single pulmonary nodule. Imaging studies showed right upper lobe PAPVR draining into the superior vena cava, even though there was no evidence of associated aSD. Our results are consistent with theirs when it comes to the prevalence of PAPVR as a major birth defect.

On the contrary, a study was conducted by Zhang et al. [14], a total of 84 patients with APVC were confirmed by surgery (n=82) or computerized tomography angiography (CTA) (n=2) in the last 6 years (2008–2014) at the Wuhan Union Hospital. TAPVC cases account for 60.7%, and PAPVC cases account for 39.3% among the 84 cases that were identified.

Differences in study populations, diagnostic methods, or referral trends could be the cause of this disparity. Furthermore, Zhang et al. [14] emphasis on cases verified by CTA or surgery may have affected the reported prevalence because these techniques may be better able to identify complicated cases like TAPVC. These variations demonstrate how different studies present and diagnose abnormal pulmonary venous connections.

In the current study, supracardiac type was the commonest subtype accounting for 20% of TAPVR cases while supracardiac type occurred in 52% of PAPVR cases.

This finding is in line with a study that was led by Karamlou et al. [15] it was found that 44% of pulmonary venous connections were supracardiac, 26% were infracardiac, 21% were cardiac, and 9% were mixed.

Our results showed that SVC was the most common site of drainage in PAPVR, accounting for 50% of cases, followed by the innominate vein at 22%. This pattern aligns with the embryological

development of pulmonary veins, where incomplete regression or malalignment of common venous channels can lead to anomalous connections. The predominance of SVC drainage likely reflects its proximity to the right pulmonary veins, facilitating anomalous connections during fetal development. Clinically, SVC drainage may result in significant left-to-right shunting, predisposing patients to right-sided volume overload and potential pulmonary hypertension.

On the contrary, Zhang et al. [14] One of the most common ways for type I drainage to reach the left innominate vein was through the vertical vein, according to their study. On the other hand, the most common way for type II drainage was.

Given that Zhang et al. [14] concentrated exclusively on cases classified by specific subtypes (type I and II) of anomalous pulmonary venous connections, these discrepancies may be the result of different patient populations. The disparities could also be caused by regional anatomical variations, institutional referral patterns, or variations in diagnostic tools. This demonstrates how drainage patterns in anomalous pulmonary venous connections vary and are complex across various studies.

In the present study, the excellent agreement between CT and ECHO in detecting ostium secondum ASD (kappa = 0.745, $p < 0.001$) highlights the reliability of both modalities in identifying this defect. This finding implies that CT can serve as a complementary or alternative diagnostic tool, particularly in cases where ECHO may be limited by acoustic window quality or patient-specific anatomical challenges.

This is consistent with a study that was led by Osawa et al. [16] In conclusion, the greatest secondum ASDs that were measured using CT and TEE were comparable in size. The rim lengths of the aortic, mitral, and tricuspid valves, the inferior vena cava, and the posterior atrium did not differ significantly, according to CT and TEE measurements.

Interestingly, another study conducted by Rao et al. [17] highlighted that while ECHO is highly effective in diagnosing and managing ASDs, certain anatomical details may be better visualized with advanced imaging techniques like MSCT.

Further, after the first TEE screening, 35 consecutive patients who were considered for possible percutaneous closure of suspected secondum ASD were assessed with gated multislice CTA, according to a study conducted by Quaife et al. [18], The most robust relationship between ICE balloon size and defect area measured using gated MPR images was found. Comparing TEE and CTA in large ASDs, the former showed weaker correlations with maximum defect size and inferior/inferoposterior rim identification.

The studies by Rao et al. [17] present findings that partially contrast with our results, emphasizing the limitations of ECHO in comparison to advanced imaging modalities like MSCT. Rao [17] highlighted that while ECHO, including transthoracic and transesophageal techniques, is highly effective for diagnosing and managing ASDs, its ability to visualize specific anatomical details, such as the rims of the defect, can be inferior to that of MSCT.

Similarly, Quaife et al. [18] demonstrated that in cases of large ASDs, CTA correlated more accurately with ICE balloon sizing than TEE, particularly in measuring maximum defect size and identifying the inferior/inferoposterior rims. These findings underscore the need for a multimodal approach to preoperative evaluation, where MSCT provides a complementary and sometimes superior anatomical delineation, especially in complex cases, which might explain why their results suggest a lower agreement between ECHO and MSCT than observed in our study.

In the evaluation of ASDs, particularly the ostium secondum type, both ECHO and MSCT play pivotal roles. ECHO,

encompassing TTE and TEE approaches, is traditionally the first-line imaging modality due to its real-time assessment capabilities and non-invasive nature. However, certain anatomical details, such as the rims of the defect, can be inferior to that of MSCT. MSCT, on the other hand, Osawa K et al. [16] offers high-resolution images and three-dimensional reconstructions, providing detailed anatomical information that is particularly beneficial in complex cases or when echocardiographic windows are suboptimal.

The integration of MSCT into the diagnostic workflow for ASDs has been shown to enhance preoperative planning. A study by Silvestry et al. [19] demonstrated that the maximum sizes of the secondum ASDs derived from CT and TEE studies were comparable. This underscores the complementary nature of MSCT and ECHO, where MSCT can provide additional anatomical insights that may influence surgical or interventional strategies.

In the current study, the excellent agreement between CT and ECHO in assessing sinus venosus ASD ($p < 0.001$) reflects the diagnostic accuracy of both modalities for this defect. ECHO, with its dynamic imaging capability, is highly effective in identifying sinus venosus anomalies. Meanwhile, CT's detailed anatomical visualization complements ECHO by providing precise mapping of associated structures.

Confirming our study, Ahn et al. [20] reported that CT provided detailed anatomical information, enabling a definitive diagnosis of complex anomalies, while ECHO required careful use of multiple windows and contrast to achieve comparable accuracy. Both studies emphasize the importance of CT's superior spatial resolution for complex cardiac anomalies, while also acknowledging ECHO 's dynamic imaging capabilities. The slight limitations of ECHO, as noted in their study, likely account for its lower sensitivity in visualizing associated venous abnormalities, underscoring CT's complementary role in surgical planning.

Supporting our results, Mamatov et al. [21] found that cardiac CT provided definitive anatomical details of the SVASD (1.9 × 2.1 cm) and PAPVR, while TEE accurately measured the defect size (1.83 × 1.8 cm) and identified associated right heart enlargement and a dilated coronary sinus. The study highlighted the superior spatial resolution of CT in delineating complex anomalies, similar to our findings.

In our study, the moderate agreement between CT and ECHO in assessing APVC cases suggests that while ECHO provides valuable initial mapping, CT offers superior anatomical detail for complex venous anomalies. This discrepancy can be attributed to the inherent limitations of ECHO, such as operator dependency and restricted visualization of posterior and extracardiac structures, compared to CT's high spatial resolution and 3D reconstruction capabilities

This finding aligns with a study that was conducted by Osama et al. [22] According to the preliminary results of the study, when done properly, MSCT can replace diagnostic cardiac catheterization for anatomical delineation and even supplement ECHO. In patients where the extra-cardiac vascular anatomy could not be clearly identified by ECHO, MSCT angiography was a valuable primary investigation tool. With a sensitivity of 100% and a specificity of 100%, MDCT accurately depicted the two types of pulmonary venous anomalies—TAPVR and PAPVR—in the prior research. For both results, ECHO had a 50% specificity.

Additionally, a study was conducted by Jiang et al. [23], it was determined that the left atrium, left ventricle, right ventricle, and RV measures were accurately measured by DSCT and TTE in good agreement (bias 0.3±5.05mm, -

0.3±4.50mm, 5.8±14.15mm, and 1.1±5.95mm, respectively).

Intriguingly, a study was led by Bu et al. [24], it was revealed that TTE had a sensitivity of 90.6%, specificity of 99.8%, positive predictive value of 99.0%, and negative predictive value of 98.4% for the diagnosis of CHD, whereas MSCT had a sensitivity of 97.2%, specificity of 99.8%, positive predictive value of 99.0%, and negative predictive value of 99.5%. Overall sensitivity was superior to that of TTE (97.2% vs. 90.6%; $P<0.05$). Additionally, MSCT was considerably more sensitive in detecting extracardiac vascular abnormalities (92.0% vs. 68.0%; $P<0.05$).

It's worth mentioning that the study conducted by Bu et al. [24] reported that MSCT had a significantly higher sensitivity than TTE overall (97.2% vs. 90.6%; $P<0.05$) and was much more sensitive in diagnosing extracardiac vascular abnormalities (92.0% vs. 68.0%; $P<0.05$). These results indicate a lower level of agreement between MSCT and ECHO than what we observed, suggesting that MSCT may outperform ECHO to a greater extent in certain contexts. The discrepancy between Bu et al.'s findings and ours may be attributed to differences in the patient population, as their study focused exclusively on young children with complex CHD, whereas our study included patients across a broader age range with anomalous pulmonary venous connections. Additionally, the higher complexity of CHD in their cohort might have magnified the differences in diagnostic capabilities between MSCT and TTE.

However, Silvestry FE et al. [19] the choice between ECHO and MSCT should be individualized, considering factors such as patient age, anatomical complexity, and the specific clinical question at hand. While ECHO remains indispensable for functional assessment and initial diagnosis, MSCT serves as a valuable adjunct, especially in scenarios where detailed anatomical delineation is required. This multimodal imaging approach ensures a comprehensive evaluation, facilitating optimal patient management.

The limitations of the study were that the study was carried out on a small sample size of 50 patients, which may limit the generalizability of the findings to a larger population and ECHO results are highly dependent on the operator's skill and experience, which may influence the agreement with MSCT findings.

Conclusions

This study demonstrated that DSCT is a reliable tool for the preoperative assessment of APVC, it showed excellent agreement with TTE in detecting ostium secondum ASD and sinus venosus ASD. DSCT provided superior anatomical detail for pulmonary vein morphology, drainage sites, and obstruction, PAPVR cases were more than TAPVC cases and the supracardiac subtype was the most frequent. Additionally, DSCT effectively evaluated vertical vein obstruction highlighting DSCT's diagnostic precision and complementary role to TTE in guiding surgical planning for APVC.

Therefore, future studies should involve larger sample sizes to enhance the generalizability of the findings, conducting multicenter studies involving diverse geographical locations and populations to improve the generalizability of findings and future research should compare MSCT with other advanced imaging techniques, such as MRI, to assess relative strengths and limitations in diagnosing APVC and related anomalies.

List of abbreviations

APVC: aberrant pulmonary venous connection;
DSCT: dual-source computed tomography;
TTE: trans-thoracic echocardiography;
CT: computed tomography;
MDCT: multi detector CT;
ECHO: echocardiography;
ASD: atrial septal defect;
RA: right atrium;

TAPVC: total anomalous pulmonary venous connection;
APVR: anomalous pulmonary venous return;
MDCTA: multidetector computed tomographic angiography;
MRI: magnetic resonance imaging;
CHD: congenital heart disease.

Declarations

Ethics approval and consent to participate:

This study was approved by the Department of Radio-Diagnosis at Benha University Hospital and AL-Nas Hospital for children from April 2023 to November 2024 (MD 13-3-2023). An informed written consent was obtained from the patients.

Consent for publication: All cases participating in this investigation provide informed consent for the publication of the data collected here.

Availability of data and material: The data supporting the present findings are contained within the manuscript.

Competing interests: None.

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Authors' contributions:

All authors reviewed and accepted the final manuscript. H.E.E. and I.M.M.S., A.E.A.A. and A.S.A.E. developed and oversaw the research; A.S.A.E. and H.E.E. managed gathering the information. A.E.A.A. and I.M.M.S. conducted analysis and interpretation of the information. All authors contributed feedback on the manuscript during different phases of its development. The final paper was written, revised, and edited by A.S.A.E. (corresponding author).

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