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Original Research Article

Role of multi-detector computed tomography in congenital heart diseases

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ABSTRACT

Background: The study aimed to assess sensitivity, specificity and accuracy of CT scan in diagnosing various cardiovascular anomalies in patients with complex congenital heart disease; to obtain additional information in pre-operative patients, inconclusive on echocardiography; and to compare results of multi-detector computed tomography (MDCT) with cardiac catheter angiography (CCA) in accurately delineating the cardiovascular morphological features and to determine if MDCT can replace diagnostic CCA in evaluation of complex CHD.
Methods: In this prospective, comparative, single-centre study, a total 50 patients were included in the study aged between 6 days to 17 years. All patients were referred by pediatric cardiologists between August, 2014 and November, 2016. All patients had undergone initial echocardiography and final diagnosis was confirmed by comparing MDCT data with CCA.
Results: Total of 177 cardiovascular anomalies are found in our study of 50 patients out of these 3 cases of VSD and one case of ASD was missed on CT angiography and its overall accuracy as compared to catheter angiography was found to be 97.1% Its accuracy in evaluation of TOF, DORV, TAPVC, TA TGA, COA, right sided aortic arch, MAPVC, persistent SVC, PDA, PS, vascular sling and coronary cameral fistula was 100%.
Conclusions: The MDCT is found comparable to CCA in the diagnosis of extra cardiac vascular anomalies but the overall sensitivity in the diagnosis of intra-cardiac anomalies is little lower. It can be used as a substitute to CCA in complex CHD and is very helpful tool in preoperative planning and postoperative follow-up.

Keywords: Angiography, Congenital heart disease, Diagnosis, Multi-detector computed tomography

INTRODUCTION

Congenital heart disease (CHD) is one of the most prevailing congenital anomalies, affecting 4-10/1000 live births, of which 50% are complex CHD.[1] An accurate and complete evaluation of the cardiac and extra-cardiac vascular anatomy is essential for diagnosis and for planning the management of patients with complex CHD.[2] Echocardiography has been the foremost method for diagnosing CHD due to its non-invasive nature, convenience, ability to delineate cardiac morphology and measure blood flow using Doppler technique.[1] Diagnostic cardiac catheter angiography (CCA) has been recognized as the gold standard for diagnosing neonatal CHD. The CCA is an invasive procedure and is limited by catheter related complications, need for general anesthesia, high doses of ionizing radiation and iodinated contrast material. Moreover, the overlapping of pulmonary and

systemic circulations might confuse the picture of a complex anatomy.[3]

The recent diagnostic advancement, multi-detector computed tomography (MDCT) serves as a rapid, non-invasive modality with good spatial resolution. It is gradually becoming the modality of choice for diagnosis, management planning and preoperative assessment of patients with complex CHD. It is also helpful for post-operative evaluation of complications. The MDCT allows volume acquisition in a short period of time, even for neonates and infants, thus significantly reducing respiratory artifacts and sedation doses for pediatric patients. In older children and adults, the increased volume-coverage speed provides very comfortable breath-hold times of 5-10 s, during which the thorax can be covered with ECG gating at the maximum possible resolution.[2] Moreover, contrast material-enhanced ECG-gated CT angiography permits remarkable visualization of normal valve morphologic features and function, and also congenital or acquired structural valvular abnormalities.[4] CT angiography simultaneously assesses the coronary arteries, which may prove valuable in surgical planning.[5]

However, there are few disadvantages of MDCT angiography in evaluation of CHDs like; radiation exposure, use of iodinated contrast material and lack of functional information (e.g., right ventricular function, pulmonary regurgitation fraction). On the other hand, measures to reduce radiation exposure are evolving, including reduction of tube current based on weight and size, modulation of tube current depending on anatomic position or phase of cardiac cycle (ECG-modulated pulsing), or reduction of tube voltage.[6] The study aimed to assess sensitivity, specificity and accuracy of CT scan in diagnosing various cardiovascular anomalies in patients with complex CHD; to obtain additional information in pre-operative patients, inconclusive on echocardiography; and to compare results of MDCT with cardiac catheter angiography (CCA) in accurately delineating the cardiovascular morphological features and to determine if MDCT can replace diagnostic CCA in evaluation of complex congenital heart diseases.

METHODS

Study design and patients

In this prospective, comparative, single-centre study, a total 50 patients were included in the study aged between 6 days to 17 years. All patients were referred by pediatric cardiologists between August, 2014 and November, 2016, to perform CT angiography examination. The inclusion criteria were: patients with suspected congenital heart disease having positive/indeterminate echocardiography findings, below the age of 20 years and patients who came for follow-up evaluation of known complex congenital heart disease. Patients were excluded if they were clinically unfit/critically ill; if they had contrast sensitivity; if serum creatinine value was >1.5mg/dl.

Data collection

Study planning

Consultation with the referring physician was attempted prior to the study to discuss the clinical background of the case and delineate specific questions raised by the physician in order to understand the reason for referral and expectations of the physician from the study. Informed consent was obtained in all cases prior to inclusion in the study. Before doing CT scan, a detailed echocardiography examination was undertaken in all patients. Patients fulfilling the inclusion criteria were subjected to MDCTA followed by CCA. A brief history focused on symptoms suggesting congenital heart disease was obtained.

Patient preparation

Description of the procedure to the parents with their reassurance was done. Patients were subjected to fasting for 4-6hrs. Venous catheters (21-24 gauges) were placed in an upper limb vein or the peripheral vein of the foot. Patients who were not able to hold their breath were sedated with 0.5ml/kg of orally administered chloral hydrate.

Computed tomography technique

The 128-slice scanner (Siemens SOMATOM definition AS+) was used and scan performed from thoracic inlet to L1-L2 level. Detector collimation was 28 x 0.6mm. Slice thickness was 3 mm. Contrast medium was non-ionic, 2ml/kg in a concentration of 320mg/ml at flow rate of 2-3ml/sec. At least two phases for each patient were taken for better anatomical detail. The region of interest varied from one type of study to another. If we were imaging the aorta-e g, in a patient with surgical shunts or coarctation of the aorta-we triggered image acquisition off contrast enhancement in the ascending aorta. If we were interested in examining the pulmonary arteries, we triggered scanning off the main pulmonary artery or the right or left pulmonary artery. The approach is more complicated in the case of intracardiac shunts. If we suspect a right-to-left shunt, we trigger scanning off the right atrium, and if we suspect a left-to-right shunt, we trigger scanning off the left atrium.

Image reconstruction and post processing

We used post processing techniques in almost all the patients, particularly when we were interested in examining the great vessels, outflow tracts, and the ventricular wall. We first created 2-dimensional (2D) multiplanar reconstructions, because they are easy to do at the scanner console and provide information very quickly. More sophisticated reconstructions at the

workstation, including 3-dimensional (3D) volume renderings, maximum-intensity projections (MIP), linear or curved planar reformatting, minimum intensity projection and shaded surface display were created. The plane of the reformatted image was adjusted to correspond to the long axis of the structure of interest. Curved planar reformation was used to evaluate curved structures such as the pulmonary artery system, MIP was used mainly for evaluation of the cardiovascular structures, and minimum intensity projection was used to evaluate the airway and lung parenchyma. For three-dimensional reformatting, shaded surface display was used to evaluate the airway and lung, whereas VR was used to evaluate the cardiovascular structures. Thin-section multiplanar reformatting was used to accurately measure the diameter or an area of the structure in question.

Image interpretation

All MDCTA data were analyzed by an independent radiologist unaware of the CCA findings. Images were interpreted guided by the anatomical and segmental/sequential approach as follows: Cardiac findings include situs, AV concordance, VA concordance, great vessel relationship, defects, and size of chambers. Extra-cardiac findings include aorta, pulmonary arteries, pulmonary venous drainage, systemic venous drainage, lung fields and pleural sacs, visceral situs. Intracardiac and extracardiac anatomy as delineated by CT angiography and cardiac catheter angiography were then compared and sensitivity, specificity, accuracy, NPV and PPV were then calculated.

Statistical analysis

Categorical variables are presented as frequency and percentages. The data were analysed using Statistical Package for Social Sciences programme (SPSS Inc., Chicago, IL, US), version-15.0.

RESULTS

Fifty patients having suspicion of congenital heart disease were enrolled in this study. All the patients had undergone initial echocardiography and final diagnosis was confirmed by comparing MDCT scan data with catheter angiography. Of 50 patients, 40 were cyanotic and 10 were acyanotic. The age distribution in congenital heart diseases was from 6 days to 17 years of age (median age 2 yrs). It was observed that cyanotic heart diseases were more prevalent in <6month age group. While acyanotic heart diseases were more prevalent around 1 year of age. The study shows that cyanotic heart disease was more prevalent in males (Table 1). The study revealed that 28 (56%) male patients had levocardia and 19 female patients (38%) had levocardia. The study showed dextrocardia in 3 (6%) patients. Situs solitus was seen in 44 (88%) cases, situs inversus in 4 (8%) cases and situs ambiguous in 2 cases (4%).

Table 1: Baseline demographics of patients.

Variables	No of patients (n=50)		Total (%)
	Cyanotic (n=40)	Acyanotic (n=10)	
Age			
< 30 days	2	1	3 (6%)
1-5 months	10	0	10 (20%)
6 months-1 yrs	7	2	9 (18%)
1-5 yrs	9	2	11 (22%)
6-10 yrs	6	2	8 (16%)
11-15 yrs	4	2	6 (12%)
>15 yrs	2	1	3 (6%)
Gender			
Male	25	5	30(60%)
Female	15	5	20(40 %)

Table 2: Distribution of cardiovascular malformations into cyanotic and acyanotic complex congenital heart diseases.

Cyanotic heart diseases	No of patients (%)
Tetralogy of Fallot	15 (30%)
Double outlet right ventricle	10 (20%)
Transposition of great vessels	2 (4%)
Total anamolous pulmonary venous return	5 (10%)
Truncus arterious	4 (8%)
VSD with main pulmonary artery atresia	3 (6%)
Others	1 (2%)
Total	40 (80%)
Acyanotic heart diseases	
Coarctation of aorta	5 (1%)
PDA	1 (2%)
Coronary cameral fistula	1 (2%)
Pulmonary sling	1 (2%)
Others	2 (4%)
Total	10 (20%)

VSD-ventricular septal defect; PDA-patent ductus arteriosus

Table 2 shows the distribution of various cyanotic and acyanotic congenital heart diseases. In this study Tetralogy of Fallot and double outlet right ventricle were the most common cyanotic heart diseases. The coarctation of aorta was the most common acyanotic heart disease. Figure 1 and 2 demonstrate images of patients with TOF having different conditions. Overall 177 cardiovascular malformations were identified in this study of 50 patients on using cardiac catheter angiography (CCA) and 173 malformations were identified on using MDCT angiography (Table 3).

The correlation between MDCT angiography and CCA was assessed for various malformations (Table 4). The accuracy of MDCT angiography in TOF was 100%, in ventricular septal defect was 94%, and in atrial septal defect was 98%. Out of 177 cardiovascular anomalies, 4 (3 cases of VSD and 1 case of ASD) were missed on

MDCT angiography. So, the overall accuracy of MDCT angiography as compared to the CCA was 97.1%.

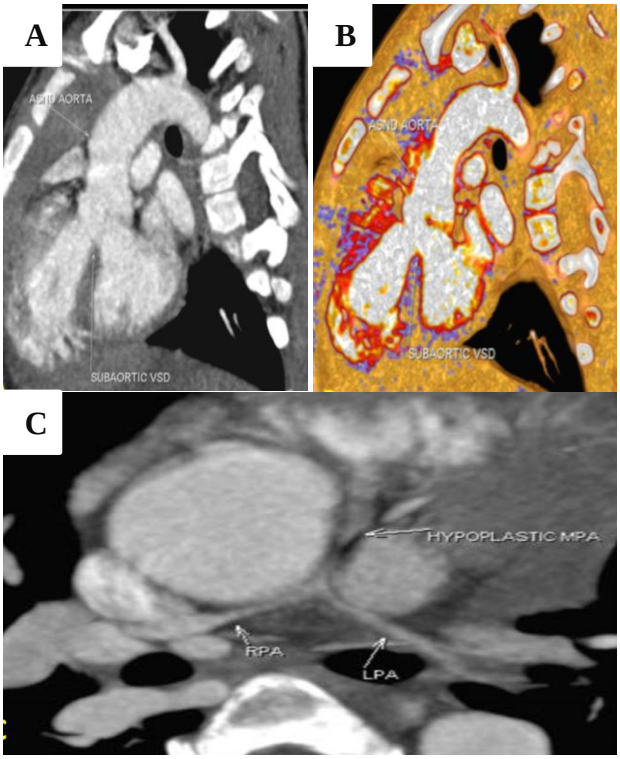

Figure 1: (A) Sagittal volume rendered and (B) Colour coded display showing sub-aortic VSD and aortic overriding in case of TOF; (C) Axial volume rendered image showing hypoplastic pulmonary artery in a patient with TOF.

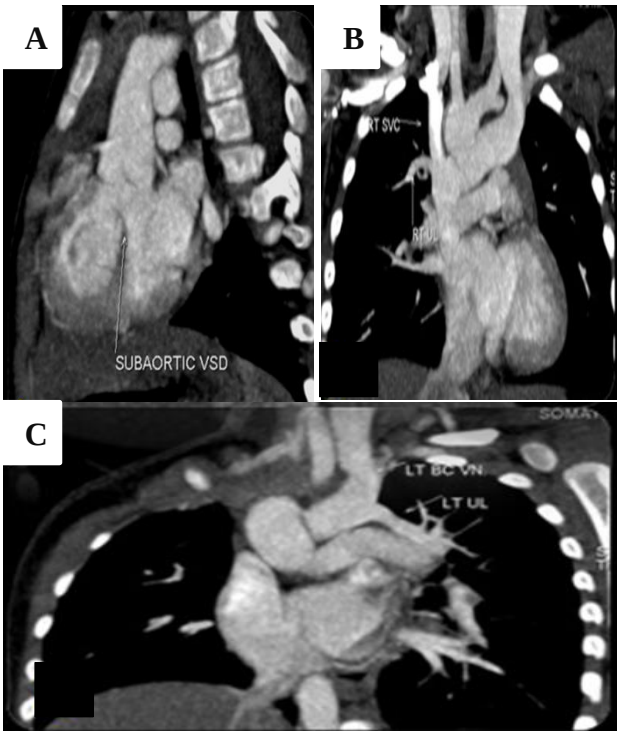

Figure 2: (A) Sagittal and (B) coronal images showing subaortic VSD in a patient of TOF with PAPVC from left upper lobe to superior vena cava.

Table 3: Distribution of cardiovascular malformations (as isolated pathology or in association) in 50 patients as diagnosed by CCA and MDCT angiography.

Cardiovascular malformation	Diagnosis by CCA in 50 patients	Diagnosis by MDCT angiography in 50 patients
Tetralogy of Fallot	15	15
Double outlet right ventricle	10	10
Transposition of great vessels	2	2
Total anomalous pulmonary venous return	5	5
Truncus arterious	4	4
VSD	36	33
ASD	9	8
PDA	14	14
Right sided aortic arch	14	14
Coarctation of aorta	5	5
Pulmonary stenosis	27	27
Coronary cameral fistula	1	1
Pulmonary sling	1	1
Persistent SVC	10	10
Multiple aorto-pulmonary collaterals	24	24
Total	177	173

VSD-ventricular septal defect; ASD-atrial septal defect; PDA-patent ductus arteriosus; SVC-superior vena cava

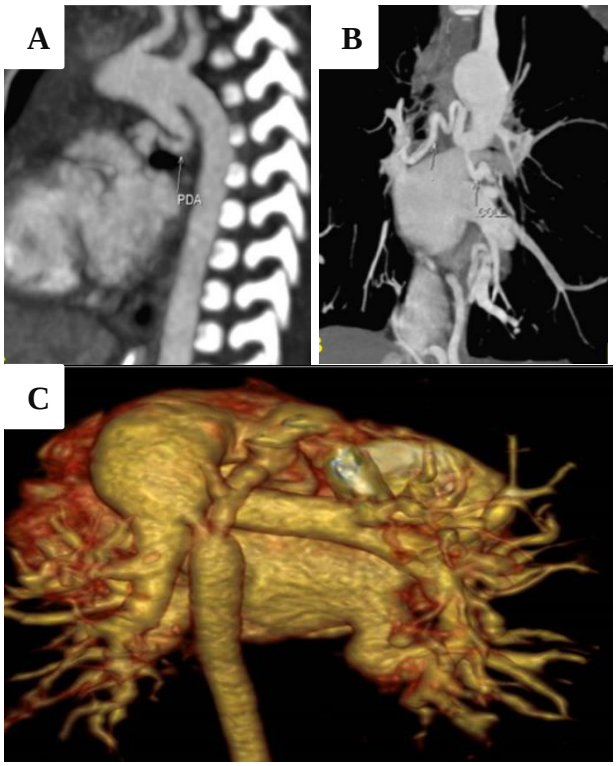

Figure 3: (A) Reformatted sagittal and (B) coronal oblique MIP image showing PDA and multiple collaterals; (C) 3D VRT images showing PDA with atretic proximal arch and coarctation of aorta.

Table 4: Correlation between MDCT angiography and CCA in assessing various cardiovascular malformations.

Cardiovascular malformation	Sensitivity (%)	Specificity (%)	Positive predictive value (%)	Negative predictive value (%)	Accuracy (%)
Tetralogy of Fallot	100	100	100	100	100
Ventricular septal defect	91	100	100	82.3	94
Atrial septal defect	88.8	100	100	97.6	98

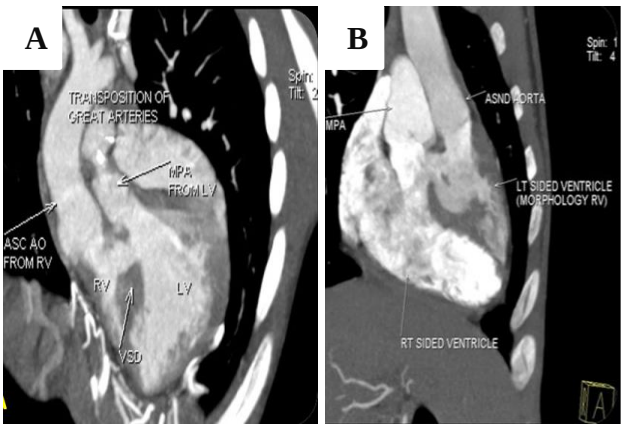

Figure 4: (A) Coronal oblique CT images showing D-TGA with aorta positioned anteriorly and towards right of pulmonary artery and (B) Arising from right ventricle and pulmonary artery from left ventricle. L-TGA where ventricular position is also inverted.

The sensitivity, specificity, positive predictive value, negative predictive value and accuracy of CT angiography in evaluation of TOF, patent ductus arteriosus (Figure 3), transposition of great arteries (Figure 4), truncus arteriosus (Figure 5), double outlet right ventricle (Figure 6), total anomalous pulmonary venous return (Figure 7 and 8), coarctation of aorta, right sided aortic arch, multiple aorto-pulmonary collaterals, pulmonary artery stenosis, coronary cameral fistula (Figure 9) vascular sling (Figure 10) and persistent superior venacava (Figure 11) were 100%, 100%, 100%, 100% and 100%, respectively.

DISCUSSION

The MDCT angiography has been an escalating modality being preferred nowadays. Not only the anatomic information, MDCT also provides hemodynamic information, including extra-cardiac, intra-cardiac shunts and valvular diseases(7). The MDCT has advantage over catheter angiography in using less radiation and contrast dose. Moreover, coronary artery anatomy gets better delineated on using MDCT. In this study of 50 patients, 40 were cyanotic and 10 were acyanotic. The congenital cardiovascular malformations diagnosed by MDCT angiography were 173 and with CCA were 177. There were 15 patients (30%) diagnosed with TOF. Previously, Grainger et al, stated that TOF is the most common cyanotic heart disease.[8] Garg et al, studied the MDCT vs. CCA in diagnosing TOF and found 100% sensitivity, specificity and accuracy.[9] Complete concordance between the diagnosis of RVOT, pulmonary artery anatomy, pulmonary annulus size, side of aortic arch and detection of collaterals was found.

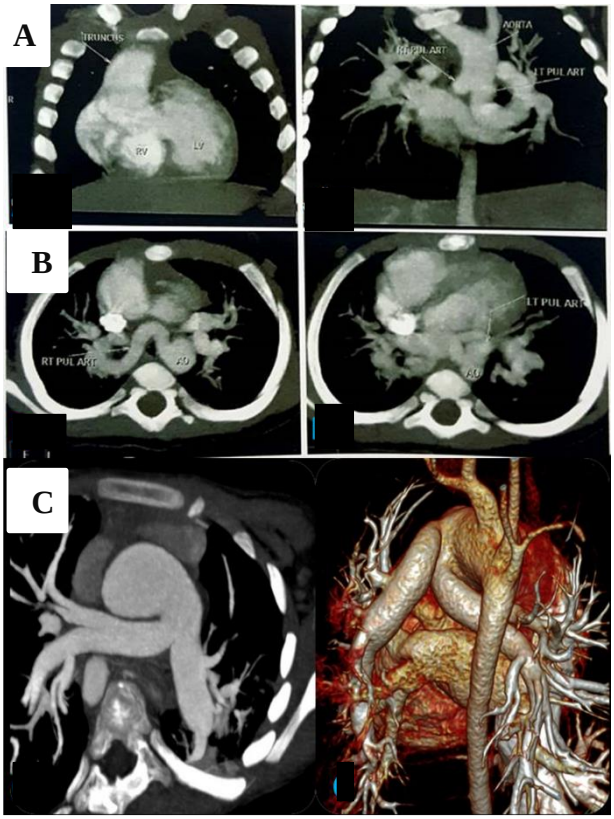

Figure 5: (A) Coronal and (B) Axial CT angiography images of type 2 truncus arteriosus showing right and left pulmonary arteries are arising from descending aorta; (C) Type 1 truncus arteriosus showing a single pulmonary trunk is arising from truncus.

In this study, we found 36 (72%) patients of VSD without other anomalies like pulmonary stenosis, MPA, TOF, and other pathologies. Of 36 cases, 3 tiny VSD in association with TOF and coarctation were missed which were subsequently recognized on CCA. In the study by Mohamad et al, for comparison of MDCT and angiography in 24 children with coarctation of aorta and other anomalies, 1 small VSD out of 4 cases was missed

and all cases of ASD were identified.[10] Garg et al, studied the MDCT vs. CCA in CHD diagnosis and found few small VSDs were missed on MDCT.[9] These findings correlate with our study.

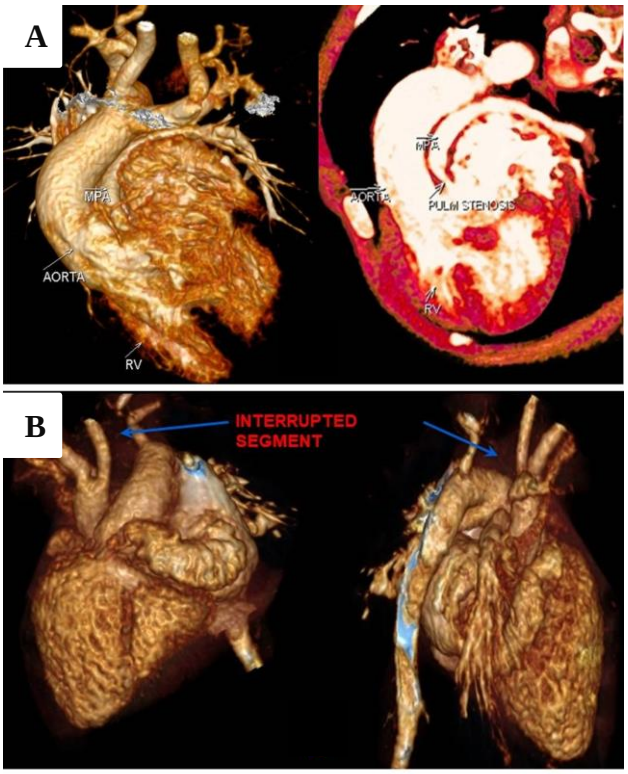

Figure 6: (A) 3D VRT images showing DORV with pulmonary stenosis subpulmonic and mid muscular VSD; (B) 3D VRT images showing interrupted arch between left common carotid and subclavian artery.

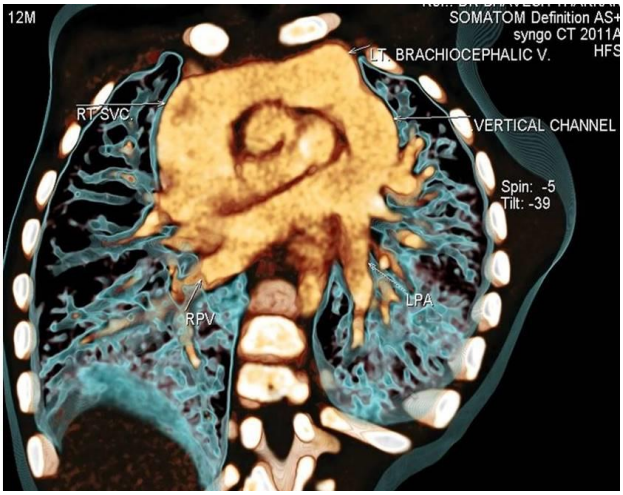

Figure 7: Supracardiac TAPVC 3D colour coded VRT images showing pulmonary venous drainage to the brachiocephalic vein via common vertical vein.

In this study, we found 9 patients (18%) of ASD without other anomalies like pulmonary stenosis, MPA, TOF, and other pathologies. Of 9 cases, 1 tiny ASD was missed which was subsequently recognized of CCA. In the study by Mohamad et al, for comparison of MDCT and CCA, 1 small ASD out of 3 cases was missed.[10] Lee et al, studied the MDCT vs. CCA found that 1 case of small ASDs was missed on MDCT.[11]

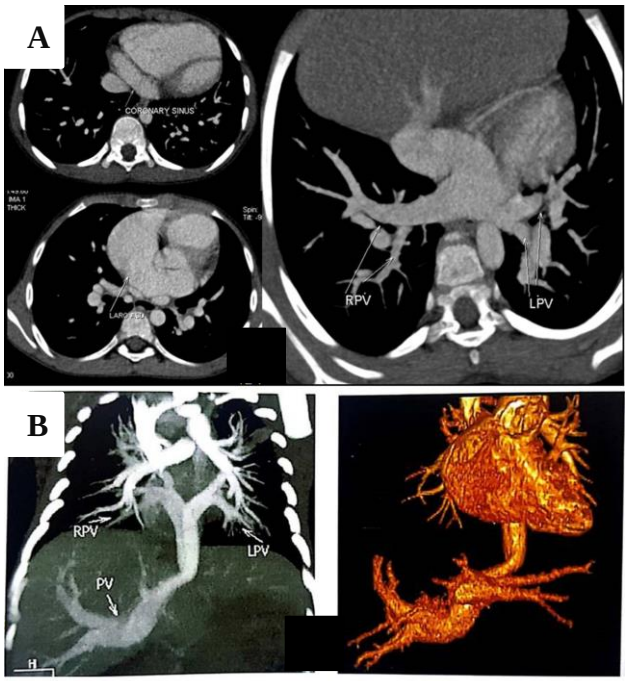

Figure 8: (A) Cardiac TAPVC axial images showing drainage of pulmonary veins into coronary sinus; (B) infracardiac TAPVC reformatted coronal MIP images and VRT revealing pulmonary veins forming common descending vertical vein which is crossing diaphragm and draining into portal vein.

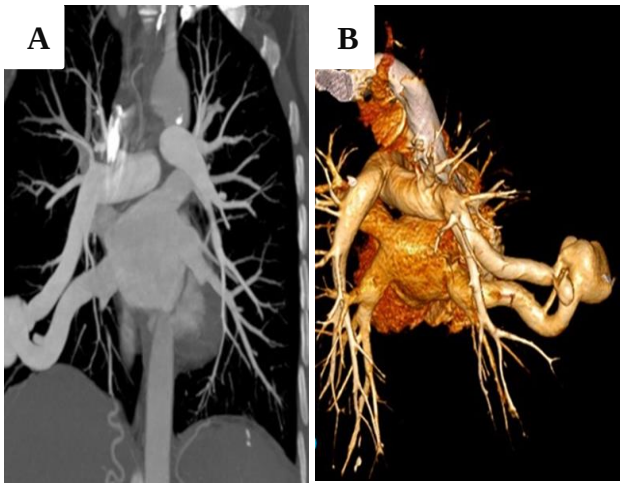

Figure 9: (A) MIP and (B) VRT pulmonary arterio-venous fistula between descending pulmonary artery and vein.

These findings correlate with our study. According to study done by Tsai IC et al, 22 patients with ASD and VSD were evaluated on CT scanner.[12] They found that

CT scan is the modality of choice for intracardiac anomalies along with good echocardiography. We believe the reason for missing tiny ASDs and VSDs on MDCT is volume averaging artifacts. Thus, we conclude that MDCT is comparable to CT angiography in the diagnosis of extra-cardiac vascular anomalies but the overall sensitivity in the diagnosis of intra-cardiac anomalies is lower than CCA.

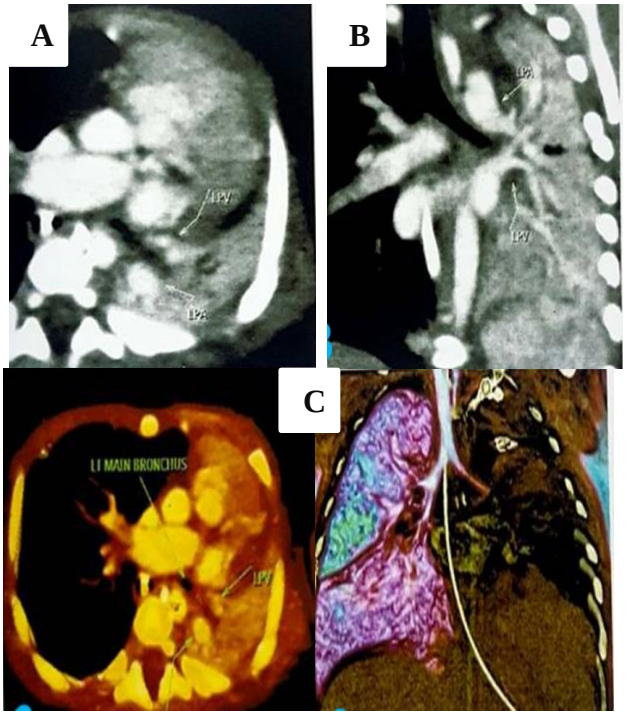

Figure 10: (A) Axial and (B) coronal and (C) volume rendered colour coded vascular sling compressing left main bronchus.

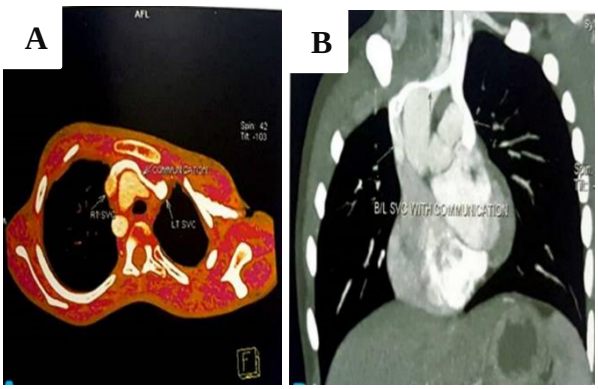

Figure 11: (A) Reformatted axial and (B) coronal MIP images showing right and anamolous left SVC communicating through innominate bridge.

The cases of congenital heart disease presenting to our tertiary hospital were complex and may have been a source of selection bias, possibly leading to overestimation of the results. This study had a small sample size may have led to misinterpretation of percentage distribution. Direct comparison of the diagnostic capabilities where not made with other imaging techniques.

CONCLUSION

The MDCT findings are more accurate as compared to echocardiography and are comparable with catheter angiography. It can be used as a substitute to catheter angiography in complex congenital heart diseases. MDCT is very helpful tool in post-operative follow up cases and for evaluation of complex congenital heart diseases. Further studies with large sample size and additional comparator groups are needed to nullify the errors and confirm and extend these findings.

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Conflict of interest: None declared
Ethical approval: The study was approved by the Institutional Ethics Committee

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