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Multi-detector computed tomography (MDCT) as a diagnostic tool in assessment of thoracic aortic anomalies in pediatric patients

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Abstract

Background: A wide variety of congenital thoracic aortic variants and pathological anomalies could be assessed recently in diagnostic and interventional radiology. Multi-detector computed tomography (MDCT) is one of the most important non-invasive diagnostic tools for their detection. The aim of the study was to evaluate role of MDCT scanning for diagnosis of thoracic aortic anatomic variants and diseases in pediatric patients.

Results: Thirty patients (15 male and 15 female), mean age (8.49 ± 20.29 months) were diagnosed with different thoracic aortic anomalies by MDCT then confirmed by surgical results. MDCT was more sensitive than echocardiography in detection of hypo plastic arch, vascular rings, interrupted aortic arch anomalies, and aortic coarctation. Both MDCT and echocardiography showed 100% sensitivity in their detection of TGA, TOF, and PDA. MDCT detected 6 cases of right-sided aortic arch while echo missed 2 cases. Different aortic arch branching patterns and coronary origin were better demonstrated by MDCT.

Conclusion: 320-Multi-detector computed tomography is a reliable tool for optimal detection of thoracic aortic anomalies and preoperative planning.

Keyword: Multi-detector computed tomography (MDCT), Thoracic aortic anomalies and variants

Background

Development of the aorta takes place during the third week of gestation. It is a complex process that can lead to a variety of congenital variants and pathological anomalies [1].

Thoracic aortic anomalies can be divided into aortic root, aortic arch, and descending aortic anomalies [2].

Echocardiography remains the first option for patients with clinical diagnosis of congenital heart disease due its excellent anatomic and functional assessment capabilities; however, it is not precise in delineation of great arteries and coronary arteries [3].

For many years, invasive angiographic techniques were considered gold standard for the assessment of thoracic aortic abnormalities. However, the complexities and complications inherent to invasive imaging have meant that more recently non-invasive techniques such as multi-detector CT (MDCT) have been increasingly used in congenital cardiovascular disorders [4].

MDCT has emerged as a fundamental tool for the diagnosis and pre-surgical work-up of thoracic aortic abnormalities due to its high spatial resolution, large area of coverage, short scan time, multi-planar reformatting, and 3D volume rendering. It is now one of the most

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widely used modalities for the detection of congenital abnormalities of the thoracic aorta [5].

The aim of this prospective study was to assess the role of multi-detector CT (MDCT) as a diagnostic and preoperative imaging modality for thoracic aortic anomalies and its variants.

Methods

Study design and population

The current prospective study included a group of 30 patients (15 male and 15 female) with echocardiographic diagnosis of thoracic aortic anomalies.

The study included any referred patient with echocardiographic diagnosis of thoracic aortic anomaly with no sex predilection; pediatric age group was included. Excluded cases were patients with known history of allergy to contrast media and patients with impaired renal function tests. Study duration was 1 year.

Preparation and protocol

All the studied patients included in the study were subjected to full history taking from their guardians, clinical examination, including vital signs monitoring before, during, and after CT examination. Renal function tests and echocardiography were checked before scanning.

Cardiac multi detector computed tomography examination

All patients were examined by 320-multidetector CT scanner (Aquilion One; Toshiba medical systems, Ohtawara, Jaban); it provided 160 mm of coverage in the z direction as the detector element consists of 320 × 0.5 mm detector. As the gantry rotation was 0.35 s, we could image the heart in a single heartbeat, and this provided excellent anatomic imaging of the whole heart, its great vessels, and coronaries.

Preparation

The procedure was described to parents for reassurance; suitable IV cannula was inserted (20 to 24 gauge) in lower limb veins (17 cases) and right upper limb veins in (13 cases) then ECG skin patches for ECG electrodes application. Sedation was done for those who were uncooperative orally with chloral hydrate (50–100 mg/kg; maximum dose, 2000 mg). Verbal instructions of breath holding were successful with one patient.

Contrast injection

All the patients were injected with non-ionic contrast medium (Ultravist 300, Schering AG, Germany or Omnipaque 300, Nycomed, Amersham); this was injected in 29 and 1 patients respectively in a dose 2 ml/kg through the peripherally inserted IV cannula using dual syringe mechanical power injector (Stellant D, Medrad, Indianola, PA, USA) with flow rate 1–1.5 ml/s increased to 3 ml/s in older children followed by saline flushing. The scanning delay was determined by a bolus tracking technique.

Manual bolus tracking was applied after 10 to 15 s from contrast material injection timing (for upper limb

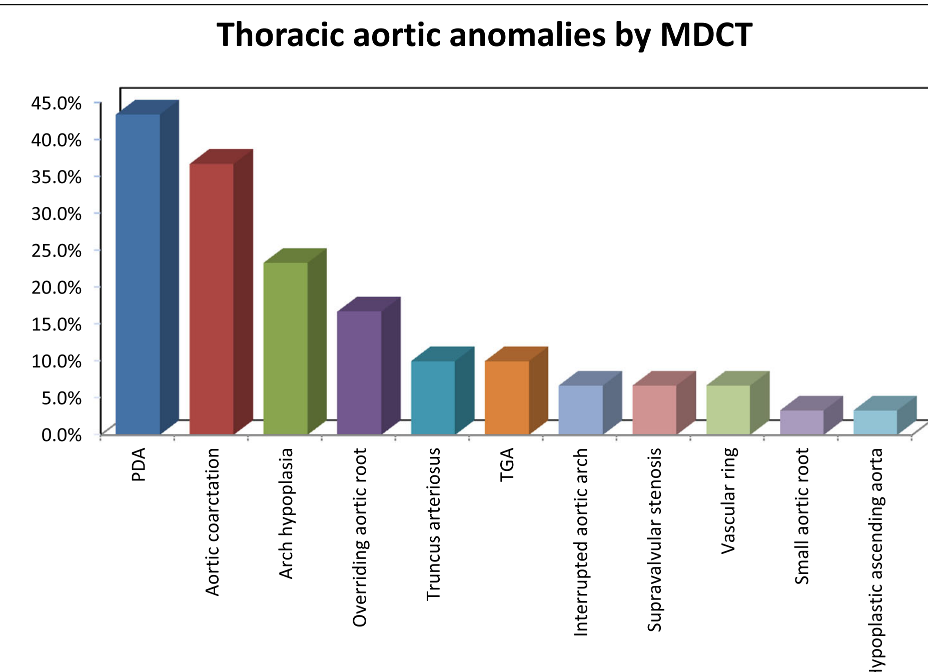

Fig. 1 Percentage of thoracic aortic anomalies detected by MDCT

Table 1 Thoracic aortic anomaly diagnosed by Echo, MDCT, and intervention/catheter

	Aortic anomaly diagnosed By					
	Echo		MDCT		Intervention/Catheter	
	No.	%	No.	%	No.	%
Interrupted Arch	1	3.3	2	6.7	2	6.7
Aortic coarctation	12	40.0	11	36.7	11	36.7
Truncus arteriosus	3	10.0	3	10.0	3	10.0
TGA	3	10.0	3	10.0	3	10.0
Arch hypoplasia	5	16.7	7	23.3	8	26.6
Vascular ring	1	3.3	2	6.7	2	6.7
Overriding aortic root	5	16.7	5	16.7	5	16.7
Supravalvular stenosis with sub aortic membrane	2	6.7	2	6.7	2	6.7
Small Aortic root	1	3.3	1	3.3	1	3.3
Hypoplastic ascending aorta	1	3.3	1	3.3	1	3.3
Patent ductus arteriosus	14	46.7	13	43.3	13	43.3
Ductus diverticulum	1	3.3	1	3.3	1	3.3

venous line) and after 20 s (for lower limb venous line), the scan is initiated after both ventricles opacification.

Monitor andemergency set

- ○ Pediatric sphygmomanometer, oxygen container with mask and extension tubing, and emergency drugs like dexamethasone for contrast allergy.
- ○ Facility to transfer the patient to the emergency room if uncontrolled complication developed.

Data acquisition

The patient lay on the CT table in supine position.

- A scanogram was obtained.
- Scan range: from the root of the neck, including the proximal aspects of the common carotid and subclavian arteries down to the level of the portal vein inferiorly. This range was important to detect associated aortic arch branch anomalies, cardiac situs, abdominal aortic coarctation, and infra-diaphragmatic type of total anomalous pulmonary venous drainage.
- Scan parameters: the patients were scanned using a single phase retrospective ECG gated CTA volume scan with a rotation time of 0.35 s and a tube voltage of 80 kV increased to 100 kV in two older children. The tube current was automatically adjusted based on the size and shape of the individual patient.

Post processing

Full volumes were reconstructed in 0.5 mm-thickness slice. Post-processing of (MDCT) scans was performed on a dedicated Vital Images work station.

Table 2 Agreement (sensitivity, specificity, and accuracy) for Echo compared to surgery/catheter angiography

Echo	Sensitivity	Specificity	PPV	NPV	Accuracy
Interrupted Arch	50.0	100.0	100.0	96.55	96.67
Aortic coarctation	90.91	89.47	83.33	94.44	90.0
Truncus arteriosus	100.0	100.0	100.0	100.0	100.0
TGA	100.0	100.0	100.0	100.0	100.0
Arch hypoplasia	62.5	100.0	100	88.0	90.0
Vascular ring	50.0	100.0	100.0	96.55	96.67
Overriding aortic root	100.0	100.0	100.0	100.0	100.0
Supravalvular stenosis with sub aortic membrane	100.0	100.0	100.0	100.0	100.0
Small Aortic root	100.0	100.0	100.0	100.0	100.0
Hypoplastic ascending aorta	100.0	100.0	100.0	100.0	100.0
Patent ductus arteriosus	100.0	94.12	92.86	100.0	96.67

Table 3 Coarctation features detected by MDCT

Coarctation features among cases with Aortic coarctation by MDCT	No.	%
Coarctation segment length		
Long	2	18.2
Short	9	81.8
Coarctation segment severity		
Mild	2	18.2
Moderate	4	36.4
Severe	5	45.5
Coarctation segment Site		
Distal to LSCA origin	9	81.8
Proximal to subclavian artery origin	2	18.2
Length of coarctation segment in mm (*n* = 10)		
Min.–Max.	3.0 –9.0	
Mean ± SD.	4.82 ± 1.81	
Median	4.60	

Maximum intensity projections (MIP), three-dimensional volume rendering (VR), multiplanar (MPR), and curved planer reformations (CPR) were used to display thoracic aortic variants and malformations.

Image interpretation

Images were independently analyzed by two different radiologists both were aware of the clinical data and echocardiographic results. Finally, correlation with the operational data was done.

Standard reference

The final diagnosis was reached by comparing the imaging findings with the operative data or cardiac catheterization which were the gold standard for the diagnosis.

Statistical analysis

Data were fed to the computer and analyzed using IBM SPSS software package version 20.0 (Armonk, NY: IBM Corp). Qualitative data were described using number and percent. The Kolmogorov-Smirnov test was used to verify the normality of distribution. Quantitative data were described using range (minimum and maximum), mean, and standard deviation. Significance of the obtained results was judged at the 5% level.

Results

This study enrolled 30 patients (15 males and 15 females) with 48 thoracic aortic abnormalities, with male to female ratio (1:1). Age of the patients ranged from 2 days to 9 years.

Clinical presentations of the patients were poor feeding, dyspnea, cyanosis, congestive heart failure, failure to thrive, and recurrent chest infections.

The thoracic aortic abnormalities detected on MDCT were correlated with the diagnostic ability and the degree of certainty of echocardiography as routine evaluation technique. Both imaging modalities results were compared to either surgical intervention or conventional catheter results as a gold standard reference.

The thoracic aortic abnormalities encountered in this study by MDCT included aortic coarctation (*n* = 11; 36.7%), hypoplastic aortic arch (*n* = 7; 23.3%), overriding aortic root (*n* = 5; 16.7%), patent ductus arteriosus (PDA) either isolated or associated with other anomalies (*n* = 14; 43.3%), two of them were isolated PDA with no intra cardiac or another thoracic vascular anomaly,

Table 4 Frequency of aortic arch branching pattern detected by MDCT (*n* = 30)

Aortic arch branching pattern detected by MDCT	No.	%
Normal branching pattern	18	60.0
Left sided with abbarent right sub clavian artery	3	10.0
Left sided arch with bovine branching pattern	2	6.7
Right sided with mirror image branching pattern	5	16.7
Right sided with abbarent left subclavian artery and Kommerell diverticulum	1	3.3
Left vertebral artery arising directly from aorta	1	3.3

Table 5 Aortic arch branching patterns association with different thoracic aortic anomalies by MDCT

Aortic anomaly diagnosed By MDCT	*N*	Aortic arch branching pattern by MDCT									
		A (*n* = 18)		B (*n* = 3)		C (*n* = 2)		D (*n* = 5)		E (*n* = 1)	
		No.	%	No.	%	No.	%	No.	%	No.	%
Interrupted Arch	2	1	5.6	0	0.0	0	0.0	1	20.0	0	0.0
Aortic coarctation	11	10	55.6	0	0.0	1	50.0	0	0.0	0	0.0
Truncus arteriosus	3	2	11.1	0	0.0	0	0.0	1	20.0	0	0.0
TGA	3	1	5.6	1	33.3	0	0.0	1	20.0	0	0.0
Arch hypoplasia	7	5	27.8	0	0.0	2	100.0	0	0.0	0	0.0
Vascular ring	2	0	0.0	0	0.0	0	0.0	0	0.0	1	100.0
Overriding aortic root	5	1	5.6	2	66.7	0	0.0	2	40.0	0	0.0
Supravalvular stenosis	2	1	5.6	1	33.3	0	0.0	0	0.0	0	0.0
Small Aortic root	1	1	5.6	0	0.0	0	0.0	0	0.0	0	0.0
Hypoplastic ascending aorta	1	1	5.6	0	0.0	0	0.0	0	0.0	0	0.0
Patent ductus arteriosus	13	9	50.0	0	0.0	1	50.0	3	60.0	0	0.0
Ductus diverticulum	1	1	5.6	0	0.0	0	0.0	0	0.0	0	0.0

A: Left sided with normal branching pattern
B: Left sided with abbarent right sub clavian artery
C: Left sided arch with bovine branching pattern
D: Right sided with mirror image branching pattern
E: Right sided with abbarent left subclavian artery and Kommerell diverticulum

truncus arteriosus (*n* = 3; 10%), supra-valvular stenosis with sub-aortic membrane (*n* = 2; 6.2%), vascular ring (*n* = 2; 6.2%), interrupted arch (*n* = 2; 6.2%), small aortic root (*n* = 1; 3.3%), and hypoplastic ascending aorta (*n* = 1; 3.3) (Fig. 1).

Echocardiography missed one aortic interruption case, one vascular ring case, and two cases of arch hypoplasia which were detected by MDCT and confirmed by aortic angiography.

MDCT missed one case of arch hypoplasia which was detected by conventional catheter.

Both echocardiography and MDCT detected correctly all cases of transposition of great arteries (TGA), truncus arteriosus, overriding aortic root, small aortic root,

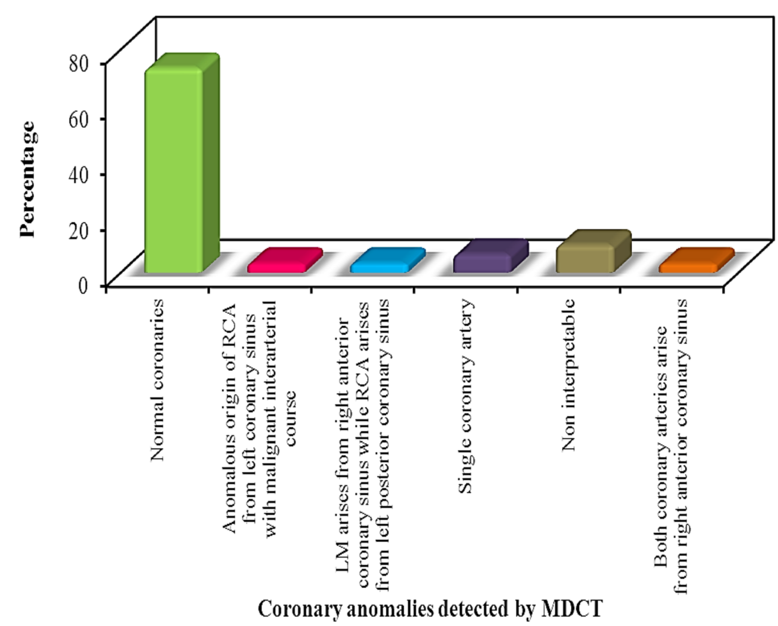

Fig. 2 Coronary anomalies detected by MDCT (*n* = 30)

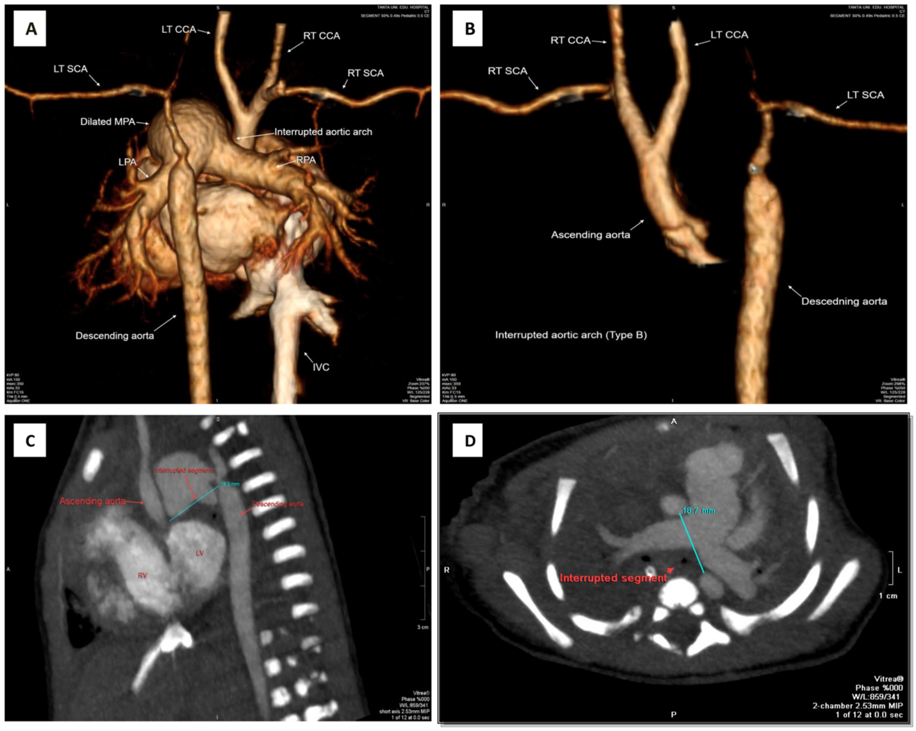

Fig. 3 A case of interrupted aortic arch type B aged 2 days presented with failure to thrive. **a** Volume rendered image of the heart and great vessels with interruption of aortic arch distal to left common carotid artery, descending aorta arising from a small PDA connecting it to main pulmonary trunk with focal coarctation at ductal site. **b** Volume rendered image of thoracic aorta with type B interruption. **c** Sagittal MIP image showing length of interrupted segment of aortic arch. **d** Axial MIP image showing length of interrupted segment of aortic arch

patent ductus arteriosus, and supra-valvular stenosis with sub-aortic membrane (Tables 1 and 2).

In this study, MDCT detected 6 cases of right-sided aortic arch confirmed by conventional catheter with 100% sensitivity, while echocardiography detected 4 case of right-sided arch missing 2 cases with 60% sensitivity.

The site, degree, and the length of the coarctation were reliably described by multi-planar and three dimensional MDCT angiography images (Table 3).

In this study, truncus arteriosus type IV represented 66.6% of truncus arteriosus cases. All cases with aortic interruption were of type B.

Normal arch branching pattern was described in 60% of cases followed by right-sided aortic arch with mirror image branching pattern in 16.7% of cases (Table 4).

The association between aortic arch branching patterns and different aortic anomalies detected by MDCT was tabulated and showed that abnormal branching patters were more frequent in cyanotic anomalies (Table 5).

In this study, 73.3% of patients had normal origin of coronaries confirmed by conventional catheter; MDCT failed to detect coronaries origin in 10% of cases (Fig. 2).

Discussion

Multi-detector computed tomography and spiral CT are widely used in diagnosis of thoracic aortic diseases. A CT scan is simple, non-invasive, and quick. Contrast administration adds more information about cardiovascular system and extra-cardiac vasculature and thoracic structures like tracheal and esophageal abnormalities [4, 6].

In the current study, all patients were sedated by chloral hydrate (50–100 mg/kg; maximum dose, 2000 mg) apart from one case aged 9 years who responded well to verbal instructions. No sedation-related complications were encountered in the study. This was the same as Kimura-Hayama et al. [7] (Figs. 3, 4, and 5).

Cases with aortic coarctation were correctly described as regards coarctation segment length, location, extend of stenosis, and extent of collaterals formation using axial, sagittal oblique MIP, volume-rendered images. Percentage of stenosis was calculated but it is not useful for visualizing the aortic gradient which agreed with Chen et al. [8] Türkvatan et al. [9], and Al-Azzazy et al. [10].

In this study, the length of the coarctation was short in 9 cases (81.8%) and long in 2 cases (18.8%). The

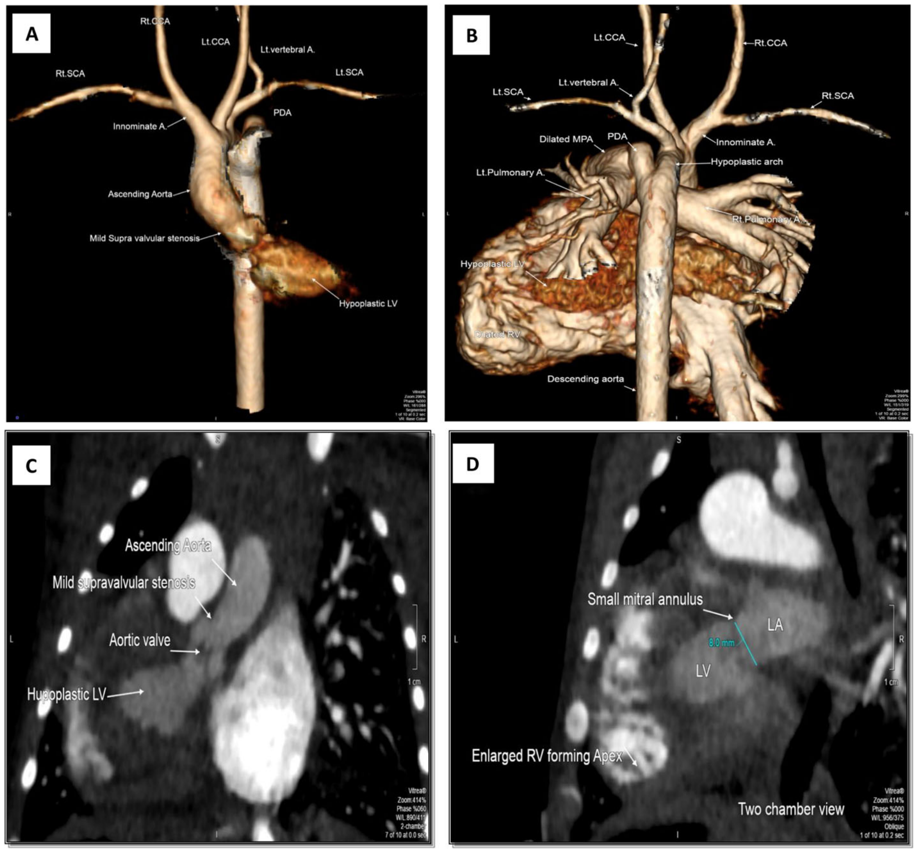

Fig. 4 A case of left hypo plastic heart syndrome with aortic arch hypoplasia aged 9 days presented with failure to thrive. **a** Volume rendered image of the thoracic aorta and left ventricle showing mild supravalvular stenosis of the aortic root which arises from hypoplastic left ventricle also aortic arch hypoplasia. **b** Volume rendered image of the heart and great vessels showing a large PDA connecting aorta to pulmonary artery, left ventricular hypoplasia and right ventricular hypertrophy. **c** LVOT view showing hypoplastic left ventricle with aortic valve thickening with mild supravalvular aortic stenosis. **d** Two chamber view of the left side of heart showing small mitral annulus

length of the coarctation was considered short if the length of the narrowed aortic segment was less than 5 mm and long if the length of the narrowed aortic segment was more than 5 mm. These percentages are nearly the same as Türkvatan et al. [9], and slightly less than that of Al-Azzazy et al. [10] and Ahmed et al. [11] who had a higher percentage for short segment coarctation patients.

As regards vascular rings detected, Echo and MDCT had 50% and 100% sensitivity respectively for detection of vascular rings when compared to conventional angiography. The detected types of vascular rings were double aortic arch with right arch predominance and right side aortic arch with aberrant left subclavian which was consistent with Hamisa et al. [12] who concluded that double aortic arch and right side aortic arch with aberrant left subclavian were the commonest forms of vascular rings in their study with 100% sensitivity for MDCT in vascular rings detection.

Interrupted aortic arch (IAA) type B was the final diagnosis of two cases in this study with percentage of 6.6% which is close to percentage described by Chen et al. [8] who detected IAA percentage of 8.8% and El Dien et al. [13] who detected the same percentage of IAA type B among his cases. MDCT had 100% sensitivity for interrupted arch detection; echocardiography showed 50% sensitivity when compared to conventional angiography results.

Jia et al. [14] confirmed the importance of MDCT in detection of major aorto-pulmonary collaterals (MAPCAs) as they found that MDCT has the potential to replace preoperative catheterization as they found excellent anatomy agreement between MDCT and surgery.

In the current study, echocardiography missed detection of one case with MAPCAs which was correctly detected by MDCT and conventional angiography; this agreed with Nakhla et al. [15] who described lower echocardiography sensitivity for MAPCAs detection.

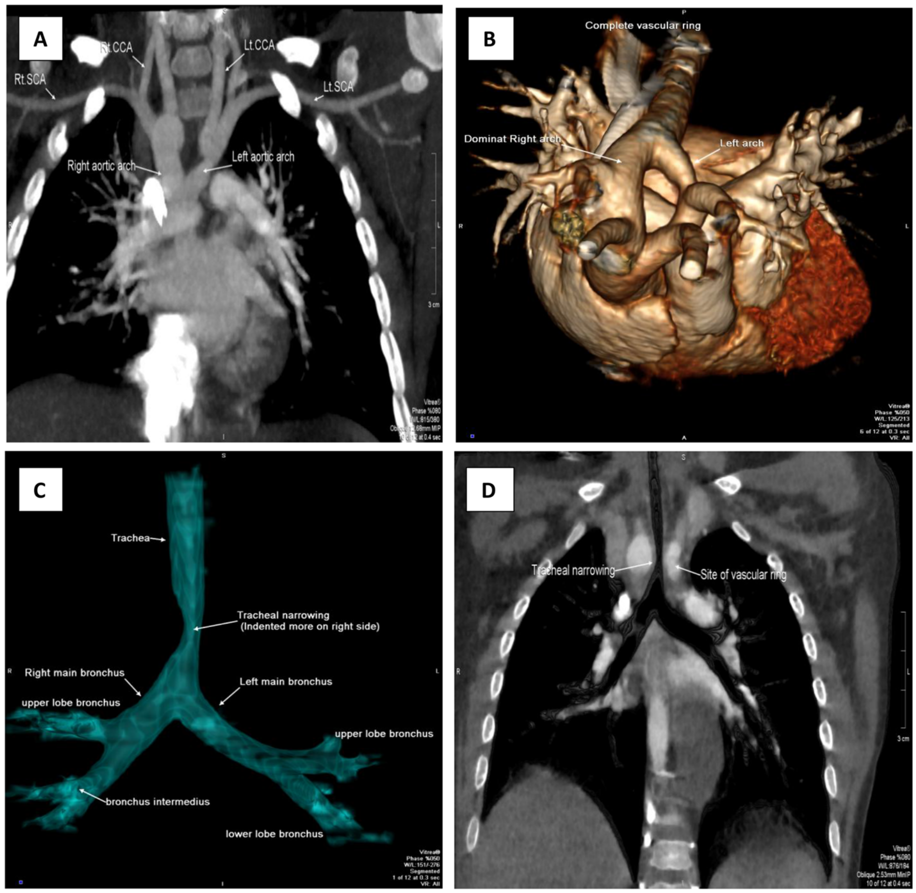

Fig. 5 A case of double aortic arch aged 9 months presented with dyspnea. **a** 2D MIP coronal image showing complete vascular ring formation by two aortic arches with the previously described branching pattern. **b** Volume rendered superior view of the heart and great vessels showing double aortic arches with right side predominance forming a complete vascular ring. **c**, **d** Tracheal narrowing at site of vascular ring shown in volume rendered image of the trachea (**c**) and in coronal MinIP image (**d**)

In this study, different aortic arch sidedness and branching patterns were described and their presence in association with different thoracic aortic pathologies was assessed using MDCT as a preoperative planning tool and was found that:

- Left-sided aortic arch with aberrant right subclavian artery had a higher incidence in females (2 cases, 13.3%) than males (1 case, 6.7%) which is similar to Piyavisetpat et al. [16] and Karacan et al. [17].
- Sixty percent of cases showed the normal branching pattern of left sided aortic arch which agreed with Zhivadinovik et al. [18].
- Left-sided aortic arch with aberrant right subclavian artery came as the third common branching pattern detected by MDCT which agreed with Celikyay et al. [19]. It was the commonest anomalous form of left-sided aortic arch detected in our study which was the same result found by Raimundo et al. [20].
- Left-sided aortic arch with bovine branching pattern came as the fourth common detected aortic arch branching pattern with a percentage of 6% of cases which was close to the percentage detected by Müller et al. [21]. It was lower than the percentage detected by Jakanani et al. [22] which was 20% of their cases.
- One case of aortic coarctation was associated with left-sided aortic arch with bovine branching pattern. The presence of this anomaly with aortic coarctation cases required the use of median sternotomy instead of lateral thoracotomy during surgical repair, which was an added preoperative planning value for MDCT.
- Left-sided aortic arch with aberrant right subclavian artery (ARSA) and right-sided arch with mirror image branching pattern were associated with cases of tetralogy of Fallot (TOF), TGA, and truncus arteriosus which agreed with Tawfik et al. [23] and Turkvatan et al. [9].

The coronary artery anatomy is important for surgical planning of complete TGA. Surgical correction of TOF requires right ventriculotomy to relieve right ventricular outflow tract (RVOT) obstruction. Hence, any major coronary artery crossing the RVOT can be accidentally damaged during surgical repair [24].

In this study, cases with TGA and truncus arteriosus had higher prevalence of coronary anomalies compared to other cases of aortic anomalies which agreed with Yu et al. [24].

This study showed that MDCT has a high diagnostic sensitivity of thoracic aortic anomalies reaching up to 100% in different variables, with the advantage of giving precise anatomical details and volume rendered images which are very helpful before surgery for accurate surgery planning.

Both Echo and MDCT had 100% sensitivity in detection of aortic root anomalies. MDCT showed higher sensitivity in detection of aortic arch and descending aortic anomalies (MDCT 100%, Echo 91.4%). Echo was a better diagnostic tool in evaluation of aortic valve anatomy as motion artifact was a drawback in three cases that could not be evaluated by MDCT.

We acknowledge that the only limitation was the retrospective ECG gating thus relatively increase the radiation dose in infants and children.

Conclusion

320-Multi-detector computed tomography is a reliable tool for optimal detection of thoracic aortic anomalies and preoperative planning.

Abbreviation

ARSA: Aberrant right subclavian artery; IAA: Interrupted aortic arch; MAPC S: Major aortopulmonary collaterals; PDA: Patent ductus arteriosus; TOF: Tetralogy of Fallot; TGA: Transposition of great arteries; VR: Volume rendered; MDCT: Multi-detector computed tomography; MIP: Minimum intensity projection; MiniP: Minimum intensity projection; LSCA: Left subclavian artery; LVOT: Left ventricular out flow; 2D: Two dimensions

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Authors' contributions

AYS have the idea of research, follow up cases, writing, publishing, and analysis the data. KIE have the final revision and supervision. OAH refer the cases and adjust any clinical problem and feedback of patients. RMD meticulous aid in writing. All authors read and approve the final manuscript.

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Availability of data and materials

The datasets used during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

This study was conducted according to the guidelines of the ethics committee of Tanta University and was approved by our institutional review board. All patients gave written informed consent to be imaged in our study. Ethics committee's reference number (39793-12-18).

Consent for publication

All patients included in this research gave written informed consent to publish the data contained within this study.

Competing interests

The authors declare that there is no competing interests.

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