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Coarctation of the aorta in adults: preoperative evaluation with multidetector CT angiography

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PURPOSE
To evaluate the reliability of 16-slice multidetector computed tomographic (MDCT) angiography for the preoperative morphologic assessment of coarctation of the aorta in adults.

MATERIALS AND METHODS
Twenty-four adult patients with clinical suspicion of coarctation of the aorta who underwent both Doppler echocardiography and MDCT angiography were included in this study. The sensitivities of diagnosis were assessed comparing MDCT and Doppler echocardiography with surgical results.

RESULTS
The overall sensitivity of three-dimensional MDCT for diagnosis of the coarctation of the aorta was 100%, which was higher than that of Doppler echocardiography (91%). The overall sensitivity of MDCT for the assessment of cardiac defects was 82%, which was lower than that of Doppler echocardiography (100%).

CONCLUSION
MDCT angiography with multiplanar and three-dimensional techniques should be the method of choice for preoperative morphologic assessment of coarctation of the aorta in adult patients.

Key words: • aortic coarctation • adult • multidetector computed tomography • angiography

Coarctation of the aorta is a congenital malformation and typically a disease of childhood and early adulthood, and there is a reduced life expectancy in patients who have not undergone correction. Without correction, the mean life expectancy of patients with coarctation of the aorta is 35 years, and 90% of untreated patients die before reaching the age of 50 years (1). Hypertensive vascular complications, cerebrovascular hemorrhages, aortic valve destruction, premature coronary artery disease, and aortic aneurysms are seen in patients with unrepaired coarctation of the aorta. In addition, dissection or rupture of the aorta is a life-threatening complication of coarctation of the aorta (2). Although the diagnosis of coarctation of the aorta can usually be made on clinical grounds, imaging is necessary to evaluate the exact anatomy of the lesion and to detect associated abnormalities. Recently, multidetector computed tomographic (MDCT) angiography has become a principal imaging modality for the evaluation of thoracic vascular anomalies because of its short acquisition time and high spatial resolution (3). MDCT angiography with multiplanar and three-dimensional techniques is the noninvasive method of choice for assessing the morphology of coarctation of the aorta, particularly to characterize the location, degree, and length of the narrowing; presence of collateral circulation; relationship to the left subclavian artery; and associated cardiovascular abnormalities. It is important to have accurate information about each of these parameters to devise surgical or interventional repair (4, 5).

The aim of this study was to evaluate the reliability of 16-slice MDCT angiography for the preoperative morphologic assessment of coarctation of the aorta in adult patients.

Materials and methods

Twenty-four adult patients (17 males and 7 females; median age, 31 years; range, 18–53 years) with clinical suspicion of coarctation of the aorta because of blood pressure gradient in the extremities and weak femoral pulses, who underwent both Doppler echocardiography and MDCT angiography, were included in this study. The symptoms of the patients were dyspnea on exertion (n = 7), chest pain (n = 6), leg weakness on exertion (n = 6), palpitation (n = 2), headache (n = 2), and epistaxis (n = 1). All MDCT images were evaluated for the site, degree and length of the coarctation; the presence of additional cardiac defects, such as patent ductus arteriosus and atrial or ventricular septal defect; and associated vascular anomalies such as an aberrant subclavian artery. The presence of an associated aneurysm and dissection of the thoracic aorta was assessed. The origin, visibility, and course of collateral vessels were also evaluated. Coarctation of the aorta was defined as greater than 25% decrease in vessel diameter. The degree of stenosis was considered severe if the ratio of the coarctation diameter to the distal descending aortic diameter was less

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than 50%. The 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. On the basis of Doppler echocardiography and three-dimensional MDCT angiography findings, surgery was performed in all 24 patients. MDCT findings were compared with both Doppler echocardiography and surgical results.

MDCT scanning technique

MDCT angiography examinations were performed with a 16-row MDCT system (Lightspeed Ultra, GE Medical Systems, Milwaukee, Wisconsin, USA). Patients were examined while supine, and images extending from base of the neck to the diaphragm were acquired during a single breathhold. Imaging parameters were as follows: tube voltage, 120 kV; tube current, 140–330 mA (varied automatically according to body size); collimation, 16 × 1.25 mm; slice thickness, 1.25 mm; increment, 0.6 mm; table feed, 27.5 mm/s; and rotation time, 0.5 s. The imaging data was acquired during an intravenous injection of 90–120 mL iodinated contrast agent (Iodixanol, Visipaque 320 mgI/mL, GE Healthcare, Milwaukee, Wisconsin, USA) at a rate of 4 mL/s. The scanning delay was determined with a bolus tracking technique. The examination was initiated 4 seconds after attenuation of the region of interest positioned in the ascending aorta reached 150 HU. For three-dimensional image reconstruction, the volumetric CT data sets were processed on a separate workstation (Advanced Workstation 4.2, GE Healthcare) with multiplanar reformatting, curved planar reformatting, maximum intensity projection, and volume rendering. Two radiologists with 4 and 11 years experience in radiology evaluated the axial source images and the two- and three-dimensional data sets for each of the 24 cases by consensus. The observers were blinded to Doppler echocardiographic findings.

Results

All coarctations were classified as postductal (localized) type, and the degree of stenosis was considered severe in 23 cases. The length of the coarctation was short in 19 cases and long in 5 cases. The coarctation was located above the origin of the left subclavian artery in 4 cases and below in 20 cases. Detailed features of 24 patients are shown in Table. Whereas all coarctations were diagnosed correctly by multiplanar and three-dimensional images

Table. Detailed features of 24 patients with coarctation of the aorta

No.	Age	Sex	Site of CoA	Degree of CoA	Length of CoA	Collateral vessels	PDA	VSD	ASD	Aortic aneurysm	Aortic dissection	Vascular anomaly
1	36	F	Below the LSA	Severe	Long	+	-	-	-	-	-	-
2	20	M	Below the LSA	Severe	Short	+	3 mm	-	-	-	-	-
3	20	F	Above the LSA	Severe	Long	+	-	-	+	-	-	-
4	35	M	Below the LSA	Moderate	Short	+	2 mm	-	-	-	-	-
5	30	M	Below the LSA	Severe	Long	+	-	-	-	-	-	Double SVC
6	25	M	Below the LSA	Severe	Short	+	-	+	-	-	-	-
7	34	M	Below the LSA	Severe	Short	+	-	+	-	-	-	-
8	19	F	Below the LSA	Severe	Short	+	-	-		-	-	-
9	18	M	Below the LSA	Severe	Short	+	-	+	-	-	-	-
10	42	F	Below the LSA	Severe	Short	+	3 mm	-	-	-	-	-
11	27	M	Below the LSA	Severe	Short	+	-	-	+	-	-	-
12	25	F	Above the LSA	Severe	Long	+	-	-		-	-	-
13	18	M	Below the LSA	Severe	Short	+	-	-	-	65 mm	Type 2	-
14	48	F	Below the LSA	Severe	Long	+	-	-	-	65 mm	-	-
15	53	F	Below the LSA	Severe	Short	+	1.5 mm	-	-	60 mm	Type 2	ARSA
16	43	M	Above the LSA	Severe	Short	+	-	-		-	-	ARSA
17	30	M	Below the LSA	Severe	Short	+	-	-	-	-	-	-
18	23	M	Below the LSA	Severe	Short	+	-	+	-	-	-	-
19	46	M	Below the LSA	Severe	Short	+	-	-	-	50 mm	-	-
20	32	M	Below the LSA	Severe	Short	+	-	-		-	-	-
21	28	M	Below the LSA	Severe	Short	+	-	-	-	-	-	-
22	34	M	Above the LSA	Severe	Short	+	3 mm	-	-	-	-	BCT
23	31	M	Below the LSA	Severe	Short	+	-	-	-	-	-	-
24	27	M	Below the LSA	Severe	Short	+	-	-		-	-	-

CoA, coarctation of the aorta; PDA, patent ductus arteriosus; VSD, ventricular septal defect; ASD, atrial septal defect; F, female; M, male; LSA, left subclavian artery; SVC, superior vena cava; ARSA, aberrant right subclavian artery; BCT, bicarotid trunk.

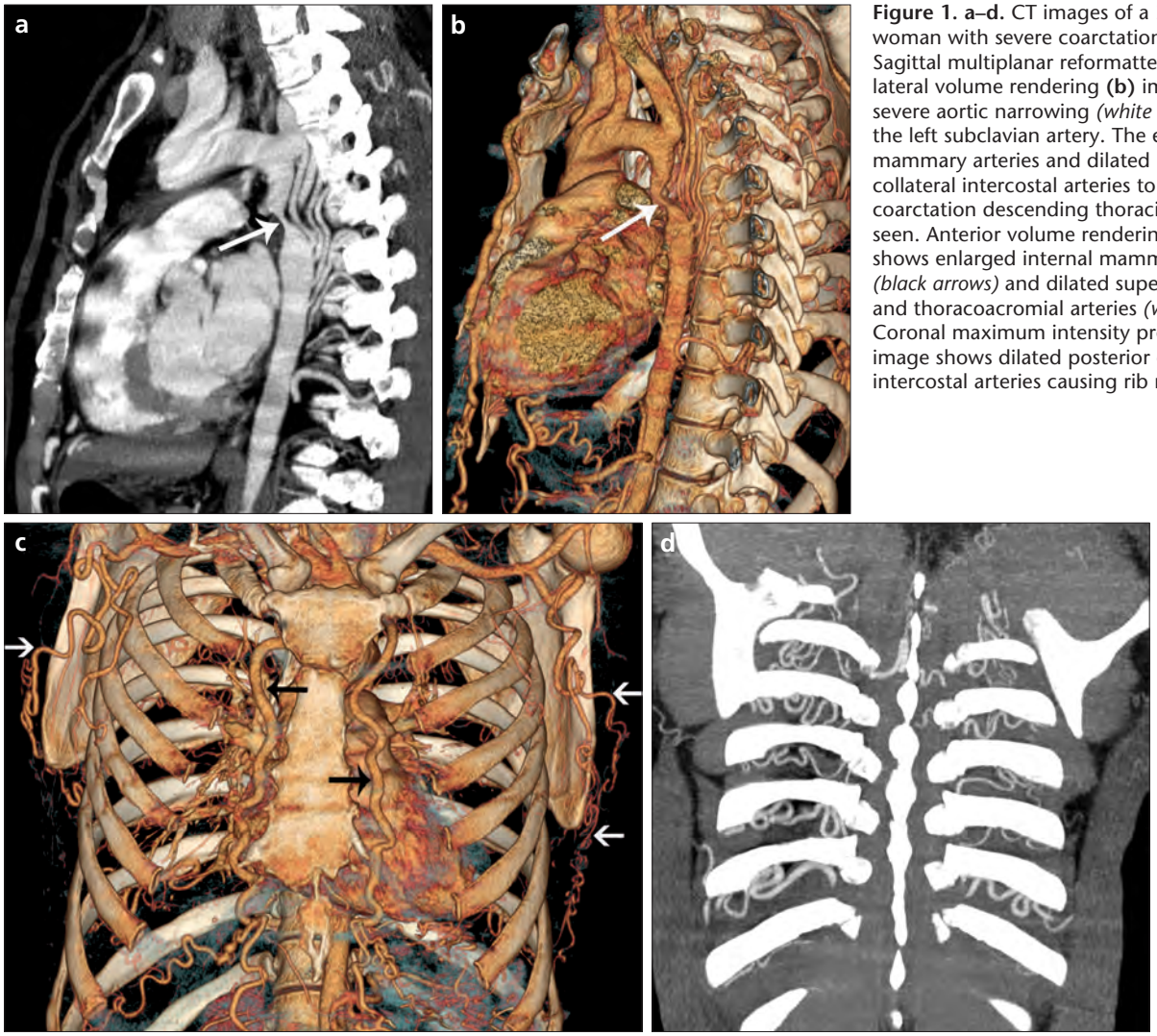

Figure 1. a–d. CT images of a 36-year-old woman with severe coarctation of the aorta. Sagittal multiplanar reformatted **(a)** and left lateral volume rendering **(b)** images show severe aortic narrowing *(white arrows)* below the left subclavian artery. The enlarged internal mammary arteries and dilated posterior collateral intercostal arteries to the post-coarctation descending thoracic aorta are seen. Anterior volume rendering image **(c)** shows enlarged internal mammary arteries *(black arrows)* and dilated superior thoracic and thoracoacromial arteries *(white arrows)*. Coronal maximum intensity projection **(d)** image shows dilated posterior collateral intercostal arteries causing rib notching.

with 100% sensitivity, two short (<5 mm) coarctations were missed by axial images, resulting in 91% sensitivity. The site, the degree, and the length of the coarctation were reliably evaluated with multiplanar and three-dimensional MDCT angiography. Overall sensitivity of MDCT angiography for diagnosis of the coarctation of the aorta was 100% (24/24), which was higher than that of Doppler echocardiography (91%, 22/24). Coarctation of the aorta was associated with additional cardiac defects in 11 cases. Five cases had patent ductus arteriosus, four cases had ventricular septal defect, and two cases had atrial septal defect. The diameters of patent ductus arteriosus ranged from 1.5 to 3 mm. All five cases with patent ductus arteriosus were correctly diagnosed by both MDCT angiography and Doppler echocardiography, with 100% sensitivity. Three of four cases with ventricular septal defect were diagnosed correctly; one case with a small ventricular septal defect was missed by MDCT. Thus the sensitivity was 75%, which was lower than that of Doppler echocardiography (100%; 4/4). One of two cases with atrial septal defect was missed by MDCT. The overall sensitivity of MDCT for the assessment of cardiac defects was 82% (9/11), which was lower than that of Doppler echocardiography (100%, 11/11). In three cases, coarctation of the aorta was accompanied by an ascending aortic aneurysm, with diameters ranging from 50 to 65 mm. In two of these three cases, a type 2 dissection was identified. In one case, a saccular aneurysm with a diameter of 65 mm just proximal to the coarctation was detected. The shape and size of the aneurysm, the presence of a dissection flap, and its spatial relations to the branch vessels were clearly depicted by MDCT. MDCT showed that coarctation of the aorta was associated with aberrant right subclavian artery in two cases, a bicarotid trunk in one case, and a double superior vena cava in one case. One of two aberrant right subclavian arteries originated from the aorta proximal to the coarctation site, and the other was just distal to the coarctation site. Collateral vessel formation was observed in all cases. The origin and course of collateral vessels were clearly seen on three-dimensional MDCT. Images of coarctation of the aorta are shown in Figs. 1–5.

Discussion

Several imaging modalities have been reported in the evaluation of coarctation of the aorta. Because of its ability to provide both anatomic and hemodynamic information, conventional angiography remains the gold

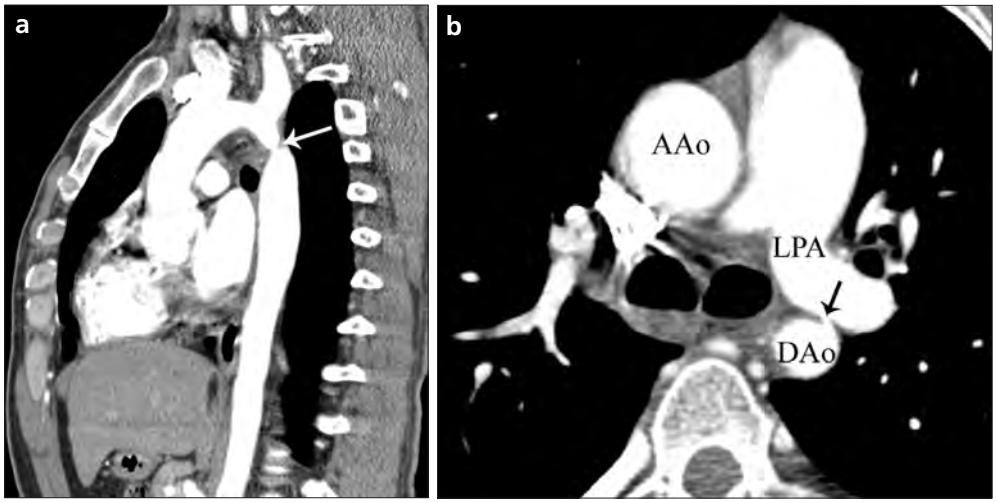

Figure 2. a, b. CT images of a 20-year-old man with severe coarctation of the aorta. Sagittal multiplanar reformatted **(a)** image shows a short segment severe aortic narrowing *(white arrow)* below the left subclavian artery. Axial image **(b)** shows a small patent ductus arteriosus *(black arrow)*. (AAo, ascending aorta; DAo, descending aorta; LPA, left pulmonary artery.)

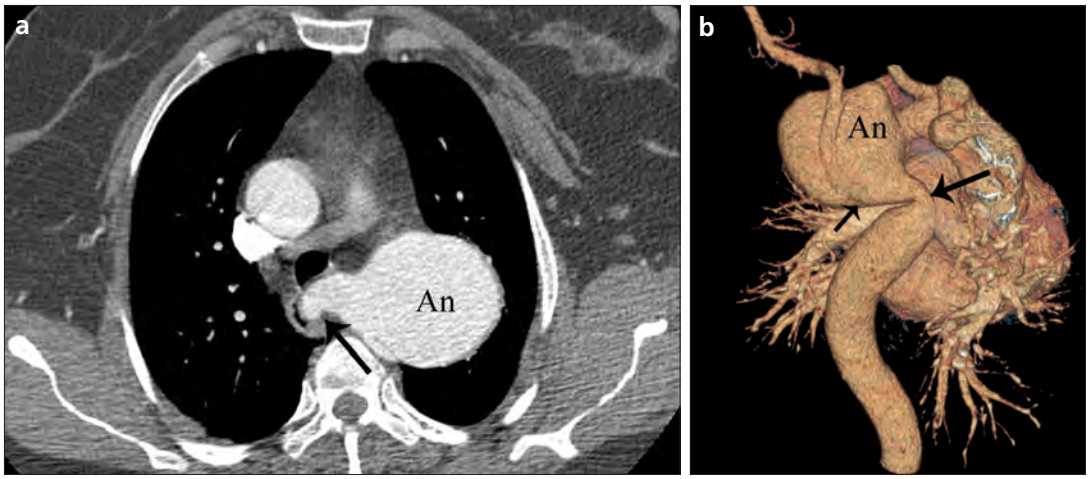

Figure 3. a, b. CT images of a 48-year-old woman with severe coarctation of the aorta. Axial **(a)** and posterior **(b)** volume rendering images show a saccular aneurysm (An) located proximal to the coarctation site *(long arrow)*. The origin of the left subclavian artery *(short arrow)* from the aneurysm is seen in **(b)**.

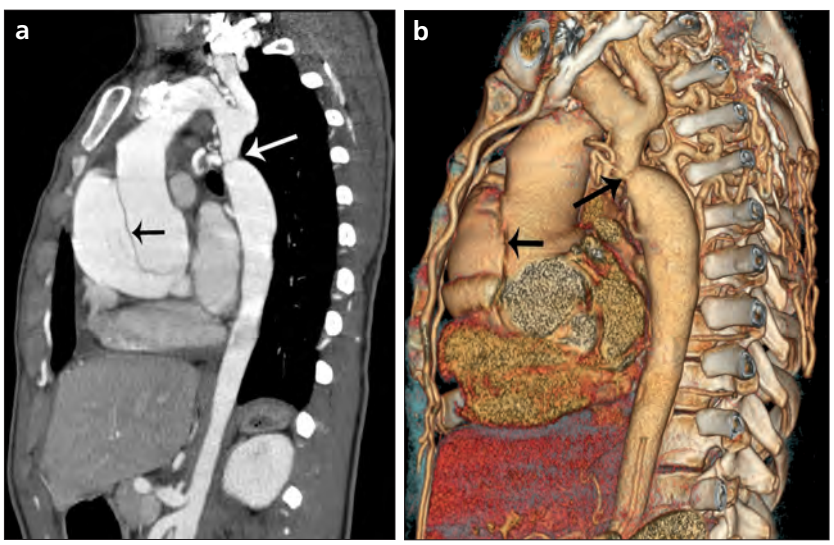

Figure 4. a, b. CT images of an 18-year-old man with severe coarctation of the aorta associated with dissection and aneurysm of the ascending aorta. Sagittal multiplanar reformatted **(a)** and left lateral volume rendering **(b)** images show a severe discrete narrowing *(long arrows)* at the aortic isthmus. An aneurysm (An) and type 2 dissection *(short arrows)* in the ascending aorta are present. Enlarged internal mammary arteries, dilated posterior collateral intercostal arteries, and descending scapular arteries are also seen in **(b)**.

standard for pretherapeutic workup of patients with coarctation. It allows pressure gradient measurement across the coarctation, visualization of the collaterals, and assessment of associated cardiac malformations; however, this technique is invasive and enhances the risk for complications imposed by the coarctation (6). Doppler echocardiography is currently the first imaging modality used, identifying the location and the severity of the coarctation and has the advantage of a noninvasive estimation of the pressure gradient across the narrowing. But it is sometimes difficult to obtain good visualization of the site of coarctation because of a poor acoustic window and the long distance between the transducer and the isthmic region. (7). Two coarctations were missed by Doppler echocardiography in this study, yielding a sensitivity of 91%.

Before the introduction of MDCT technology, magnetic resonance imaging (MRI) was frequently used for the assessment of congenital thoracic vascular anomalies because of its multiplanar capability. Contrast-enhanced MR

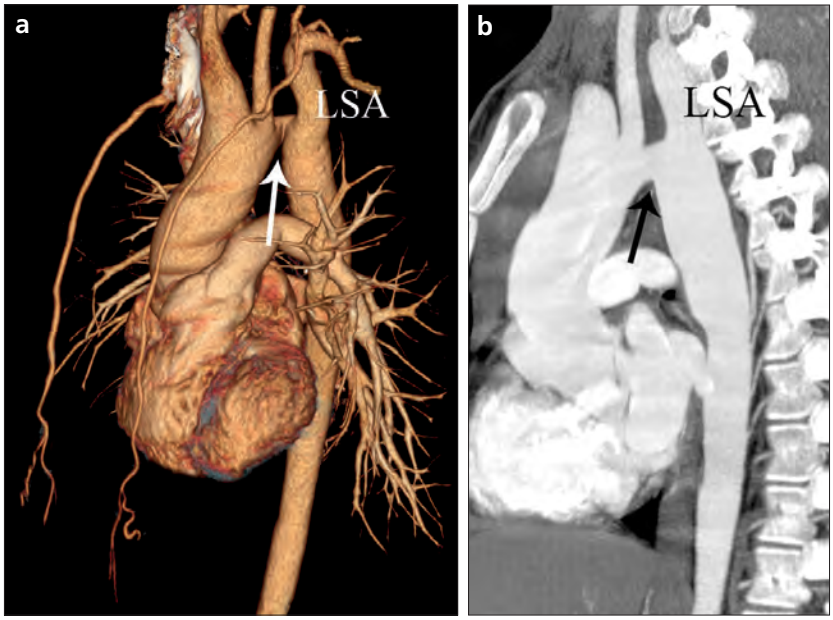

Figure 5. a, b. CT images of a 20-year-old woman with severe coarctation of the aorta. Left lateral oblique volume rendering **(a)** and sagittal multiplanar reformatted **(b)** images show severe coarctation *(arrows)* located above the origin of the left subclavian artery. The right internal mammary artery was larger than the left one. Dilated posterior intercostal arteries are also seen in **(b)**. (LSA, left subclavian artery.)

angiography is, for the most part, sufficient for evaluation of the aorta and its branches, whereas cine MRI and phase-contrast MRI allow assessment of the hemodynamic significance of the coarctation, as well as cardiac and valvular function (7, 8). When multiplanar and three-dimensional postprocessing techniques became available, the role of CT in the assessment of thoracic vascular anomalies changed. MDCT has changed not only the imaging evaluation approach to thoracic aortic anomalies but also challenged the role of conventional angiography (9–12). Compared with MR angiography, MDCT angiography has the advantage of the ability to acquire high spatial resolution in a shorter acquisition time. In addition, volume rendered and multiplanar reconstructions are better for MDCT angiography data display than MRI (13). MDCT with multiplanar and three-dimensional techniques provides morphologic images of coarctation of the aorta and its relationship to the arch vessels, as well as demonstrating collateral circulatory pathways (4, 5). But it is not useful for visualizing the aortic gradient or small cardiac malformations (4). In this study, overall sensitivity of MDCT for the assessment of cardiac defects was 82%, which was lower than that of Doppler echocardiography (100%).

On axial CT slices, the course of the aorta, the location of the coarctation, and the collateral vessels may not be clearly displayed; short segment coarctations, particularly, may be missed (14). The ability to visualize a vascular structure depends on the angle between these structures and the imaging plane. If a vessel is perpendicular to the long axis of the imaging plane, the cross-sectional diameter can be reliably displayed, but if the vessel is oblique or parallel to the imaging plane, stenosis can be missed. Underdiagnosis of coarctation on axial images is not surprising, as this abnormality is often small and its course oblique rather than perpendicular to the imaging plane (3). However, on sagittal multiplanar and three-dimensional volume-rendered images, short segment coarctations are well visualized. In our study, two short coarctations were missed on axial images but were correctly diagnosed with multiplanar and three-dimensional images. For the diagnosis of coarctation, sensitivities were 91% for axial and 100% for multiplanar and three-dimensional volume rendered images.

MDCT is an excellent means for identifying aortic aneurysm and dissection, the most serious complications of coarctation. Although the development of aneurysms proximal to the coarctation site might be expected, aneurysms may occur distal to the coarctation site, which is secondary to the turbulent flow in the region of the coarctation (15). The primary cause of death in unrepaired cases of coarctation of the aorta is aortic rupture; the location of the rupture is usually the ascending aorta (16). Although definitive diagnosis of structural aortic complications in coarctation of the aorta has traditionally rested on conventional angiography, MDCT, increasingly used a first-line investigation, can reliably display aortic complications including aneurysm formation and dissection. It allows not only an exact definition of size and shape of the aneurysm and its spatial relations to the branch vessels, but also assessment of extravasated blood in acute or subacute rupture (16).

The number of collateral vessels is generally proportional to the severity of the coarctation even if, in exceptional cases, rare collaterals may be found with tight coarctations. Collateral vessels most frequently emerge from the branches of the subclavian arteries above the coarctation and provide blood to the area below the coarctation. The main collateral pathways that develop most commonly in isthmic coarctation of the aorta include the pathway from the internal mammary artery through the intercostal arteries to the post-coarctation descending thoracic aorta; that from the thyrocervical and costocervical trunks through the thoracoacromial and descending scapular arteries to the post-coarctation descending thoracic aorta; and that from the vertebral artery through the anterior spinal artery and intercostal arteries to the post-coarctation descending thoracic aorta (17). Identification of collateral circulation is of importance before surgery to avoid ischemic medullary injury. In our study population, all cases had collateral vessel formation, and the origin and course of collateral vessels were very well displayed with three-dimensional MDCT angiography.

Although MR angiography is an excellent noninvasive method for assessment of coarctation of the aorta because it allows both morphologic and functional evaluation, it has not become a primary method in the evaluation of coarctation of the aorta because of its high cost and lack of availability.

It is usually reserved for patients for whom Doppler ultrasound fails to visualize the coarctation and estimate pressure gradient at the coarctation site. At our institution, we prefer MDCT angiography in adult patients and MRI in pediatric patients. Our surgeons are satisfied with three-dimensional MDCT angiography images for the assessment of anatomic features of coarctation of the aorta before surgery.

In conclusion, MDCT angiography is the method of choice for preoperative morphologic assessment of coarctation of the aorta in adult patients. It can easily identify the precise location and the degree of the coarctation and its relationship with the branch vessels. The presence of associated aneurysm or dissection and origin and course of collateral vessels can also be clearly depicted with MDCT. Because axial images may be insufficient for evaluation of short coarctations, multiplanar and three-dimensional images are needed in the assessment of coarctation of the aorta.

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