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Evaluation of Aortic Disease with Spiral CT Angiography and Multiplanar Reconstructions: Comparison with Catheter Angiography

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Purpose: To assess the usefulness of spiral CT angiography (CTA) in the evaluation of aortic aneurysm (AA) or dissection (AD).

Methods: Ninety-eight patients with AA (n = 78) or AD (n = 20) were examined with CTA. Imaging results were correlated with angiographic (n = 98) findings in all cases and surgical findings in AA cases (n = 64). The spiral CT angiography were analyzed by an experienced radiologist without knowledge of the result of the catheter angiography, to evaluate the same features. The catheter angiograms were individually interpreted by two experienced radiologists.

Results: In AA, all of major aortic branches were depicted on CTA except two of seven accessory renal arteries and six of 26 inferior mesenteric arteries. CTA correctly assessed aneurysm involvement of left subclavian (LSA), renal (RA), and iliac arteries (IA) in all patients. In AD, CTA correctly assessed Stanford classification in all patients, and the relationship between 70 major aortic branches and true/false lumen in all but two branches. CTA showed 23 of 30 intimal tears in double barreled AD.

Conclusion: CTA might replace catheter angiography in evaluation of AA and AD except in cases of type A dissection.

Index Terms: computed tomography - CT angiography - aorta, aneurysm - aorta, dissection - Catheter angiography

Precise delineation of anatomic changes in various aortic diseases including aortic aneurysm (AA) and dissection (AD) is crucial for the proper management and preoperative assessment of the these conditions. Catheter angiography has been considered the gold standard to evaluate the abnormalities in aortic diseases. Recently, however, spiral CT angiography that combine the advantages of conventional CT and aortography has been introduced as a noninvasive technique for the evaluation of AA and AD[1,2,3,4,5]. The purpose of this study was to determine whether CT angiography alone can provide all the information necessary for the surgical planning in patients with AA or AD, by correlating CT angiographic findings with the findings of catheter angiography and surgery.

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Materials and Methods

Patients (Table 1, 2)

Ninety-eight patients with aortic aneurysm or dissection were enrolled into the study. Of the 98 patients studied, 78 patients (57 males; 21 females; age 46-87 years, mean age 73.9 years) had thoracic (TAA) and/or abdominal aortic aneurysm (AAA). The

Table 1. Clinical characteristics of patients with aortic aneurysm (n=78)

	Thoracic aortic aneurysm (n=23)	Abdominal aortic aneurysm (n=55)
Mean age(y)	68.0	76.6
Sex		
Male	13	44
Female	10	11
Operation	14	44

Table 2. Clinical characteristics of patients with aortic dissection (n=20)

Mean age (y)	67.1	
Sex		
Male	12	
Female	8	
Stanford classification		
Type A	6	(surgery 6)
Type B	14	
Type of dissection		
Double barreled Type	15	
Thrombosed type	5	

remaining 20 patients (12 males; 8 females; age 32-97 years, mean age 67.1 years) had thoracic and/or abdominal aortic dissection. All patients underwent both catheter angiography and CT angiography within an interval of 2 weeks. Surgical correlation of the imaging findings was obtained in 58 patients with aortic aneurysm and in 6 patients with aortic dissection.

Spiral CT technique

CT scans were performed with a Siemens Somatom Plus scanner (Siemens, Erlangen, Germany). An unenhanced CT scan was initially performed to determine the starting position for spiral CT angiography, which was generally at the level of 2-3 cm above the aortic arch in patients with thoracic aortic disease, and at the level of the celiac or the superior mesenteric artery origin in patients with abdominal aortic disease. For spiral-CT angiography, 100 ml of contrast material (Iohexol, 300 mg iodine/ml) was injected at a rate of 3 ml/s in the arm vein. Scanning was commenced 20-25 seconds after the contrast injection and was obtained during a single breath hold of 30 seconds. Maximum scan time of this machine was 30 seconds and, when the first scan could not cover the whole length of the diseased aorta, the second scan was performed to cover the adjacent segment. No circulation test to evaluate the correct timing of contrast delivery was performed since, in our experience, a 20-25 seconds scan delay achieved a good contrast enhancement of the vessels in almost all cases. We used a table feed of 3-8 mm/s, 3-5 mm collimation and a pitch of 1-1.6. The 3-mm thick slices were then reconstructed from the volume data. The 3D reconstruction images were obtained with commercially available software equipped for the scanner. In all patients, the images were preprocessed to segment out bones, and maximum intensity projection (MIP) images were generated for three-dimensional display. Multiplanar reformatted images (MPR) were also obtained in all patients in whom 3D rendering was done. The images were reformatted in the sagittal, coronal, and oblique planes at 2-3 mm intervals.

Angiograhic technique

Angiographic study was performed with Siemens Angiostar (Siemens, Erlangen, Germany) equipment and Philips Integris (Philips, USA) DSA equipment. Contrast injections (Iopamidol, 300 mg iodine/ml 40ml each, 15-20 ml/s) using a power injector were performed with a 5Fr pig tail catheter to image thoracic and/or abdominal aorta. Anterior -posterior and additional views (eq. lateral or oblique) were obtained. The angiographic study was recorded on film.

Data analysis

The catheter angiograms were individually interpreted by two experienced radiologists. The following features were evaluated in all cases.

Thoracic aortic aneurysm

(1) Visualization of aortic arch branches including the right brachiocepahalic, left carotid, and left subclavian arteries.

(2) Proximal portion of the aneurysm in relation to the origin of the left subclavian artery (LSA), being classified as involved if the aneurysm involved the origin of LSA, or as not-involved if there was nonaneurysmal segment between LSA and aneurysm.

Abdominal aortic aneurysm

(1) Visualization of abdominal aortic branches including the celiac, superior mesenteric (SMA), bilateral renal (RA), and inferior mesenteric arteries (IMA).

(2) Degree of coexistent RA stenosis of moderate/severe (30-99%) or occlusion (100%).

(3) Location of proximal portion of aneurysm in relation to the RA origins, being classified either as completely infrarenal, or as juxta-/suprarenal if the upper limit of aneurysm involved the origin of at least one renal artery or extended more proximally.

(4) Distal extent of the aneurysm, being classified either as terminating above the aortoiliac bifurcation or as extending beyond it.

Aortic dissection, double barreled type

(1) Extension of the dissection (type of dissection)

(2) Visualization of intimal tears, which were divided into three groups in this study; entry (a proximal intimal tear), reentry (a distal intimal tear) and, if present, the other communicating tears.

(3) Visualization of major aortic branches including the right brachiocepahalic, left carotid, left subclavian, celiac, superior mesenteric, bilateral renal, and inferior mesenteric arteries.

(4) Relationship of major aortic branches to true/false lumen.

Aortic dissection, thrombosed type

(1) Visualization of ulcer like projection (ULP), which is defined as a localized blood-filled pouch protruding from the lumen of the aorta, showing the same degree of contrast enhancement as the aortic lumen.

(2) Visualization of major aortic branches including the right brachiocepahalic, left carotid, left subclavian, celiac, superior mesenteric, bilateral renal, and inferior mesenteric arteries.

The spiral CT angiography were analyzed by an experienced radiologist without knowledge of the result of the catheter angiography, to evaluate the same features, as described above, using the same criteria. Axial source images, MPRs and MIPs were used for the analysis.

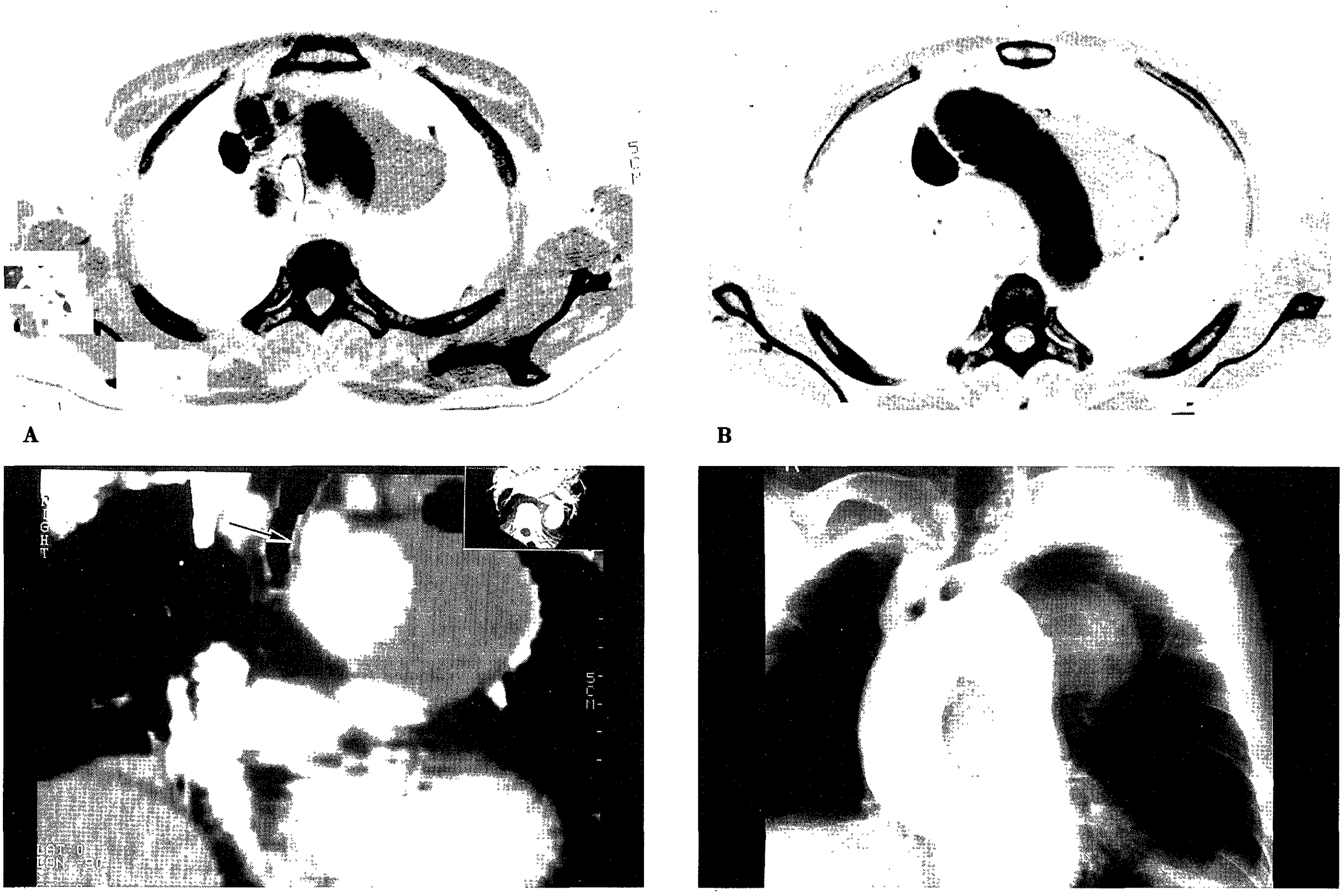
In order to establish the accuracy of spiral CT angiography in assessing each feature of AA and AD, different standards of reference were employed appropriate to each feature. Namely, operative findings were used as the standard of reference in the 58 surgical patients with AA to determine the proximal and distal extent of the aneurysm and patency of IMA. In the remaining features, catheter angiography was regarded as the standard of reference in each type of aortic disease.

Results

Thoracic aortic aneurysm

All of the major aortic arch branches, which were demonstrated by catheter angiography in 23 patients, were clearly depicted on CT angiography.

Fourteen of the 23 patients with TAA underwent surgery. Surgical findings revealed that the aneurysm involved the origin of LSA in 3 of the 14 patients. CT angiography delineated the involvement of LSA in all of the 3 patients, while catheter angiography could not delineate it in one of them (Fig. 1).



A B C D

Fig. 1. Aortic arch aneurysm.
A. B Contrast-enhanced CT shows an aortic arch aneurysm, which contain thrombus in most part of aneurysmal sac. It is difficult to determine the exact relationship between the great vessels and aneurysm on axial CT images.
C Multiplanar reconstruction reveals that the left subclavian artery is directly involved by the aneurysm (arrow).
D Catheter angiogram shows a large aneurysm in the distal aortic arch, most part of which is not filled with contrast material due to mural thrombus. It is impossible to assess exact relationship between the great vessels and aneurysm on this angiogram. At surgery, the left subclavian artery was involved by the aneurysm, and reconstruction of this artery was done.

Table 3. Performance of CT angiography in depicting abdominal aortic branches (n=55)

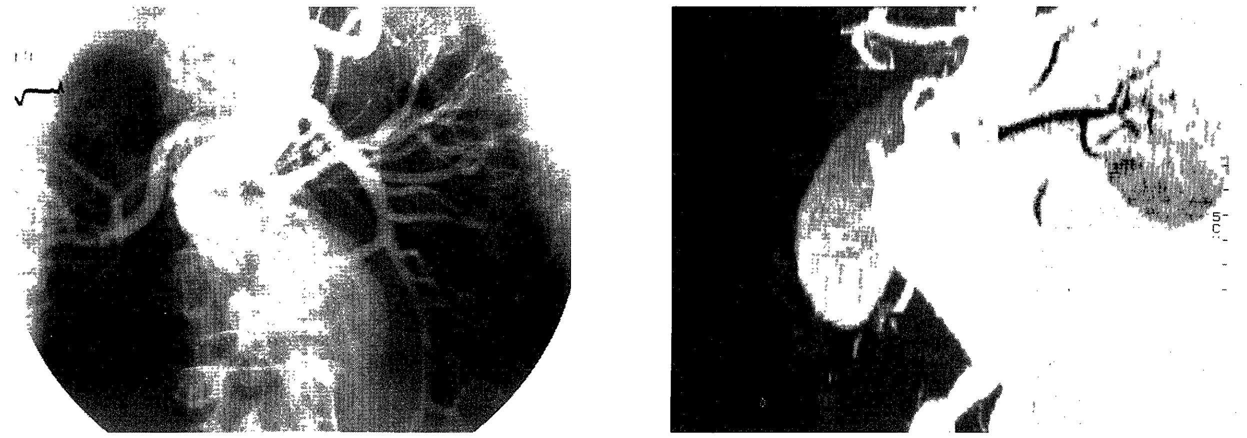
Aortic branches	CT angiography	Catheter angiography
Celiac trunk	41	55
Superior mesenteric a.	54	55
Rt. renal a.	55	55
Lt. renal a.	55	55
Accessory renal a.	5	7
Inferior mesenteric a.	27	26

Table 4. Value of CT angiography for evaluating stenosis of renal artery (n=55, 110 branches)

	Catheter angiography			
	Normal /Mild (0-29%)	Moderate /Severe (30-99%)	Occlusion (100%)	Total
CT angiography				
Normal/Mild	90	0	0	90
Moderate/Severe	12	7	0	19
Occlusion	0	0	1	1
Total	102	7	1	110

Abdominal aortic aneurysm (Table 3, 4 and 5)

At catheter angiography, a total of 253 major branches of the abdominal aorta were depicted in 55 patients (55 celiac arteries; 55 SMAs; 55 right RAs; 55 left RAs; 7 accessory renal arteries; 26 IMAs). The celiac artery was depicted in 41, and SMAs in 54 of the 55 patients at CT angiography. Fourteen celiac arteries and one SMA in the remaining patients were not included in the scan area. CT angiography showed all of the 110 RAs and 5 of the 7 accessory renal arteries, which were demonstrated by catheter angiography (Fig. 2, 3). The IMAs were depicted in 26 of the 55 patients at catheter angiography (Table 3). CT angiography showed 20 of the 26 IMAs, while the remaining 6 arteries were missed at CT angiography. Additionally, in 7 other patients in whom IMA was not depicted at catheter angiography, CT angiography



A B

Fig. 2. Abdominal aortic aneurysm.
A Catheter angiogram shows one right renal, and two left renal arteries.
B All the renal arteries are clearly depicted on a MIP image.

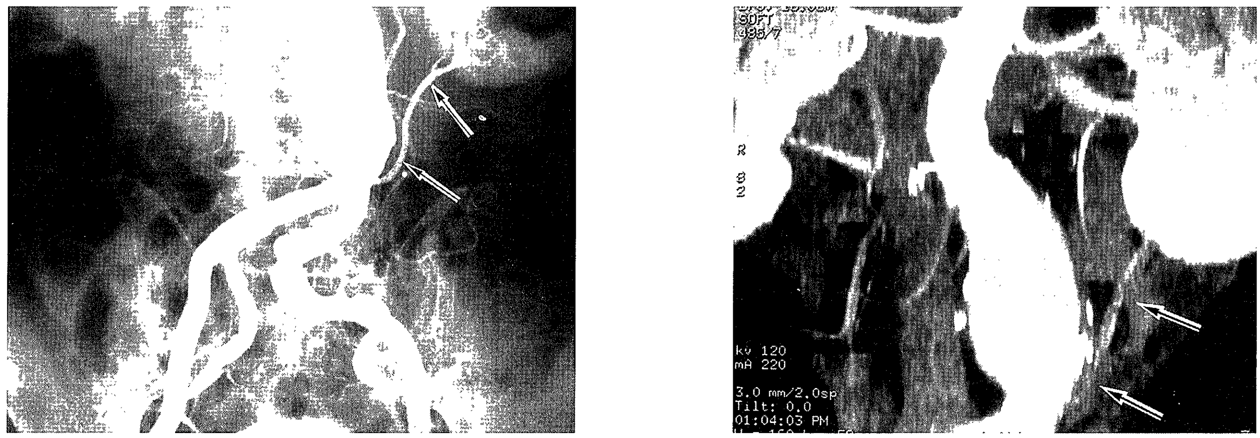


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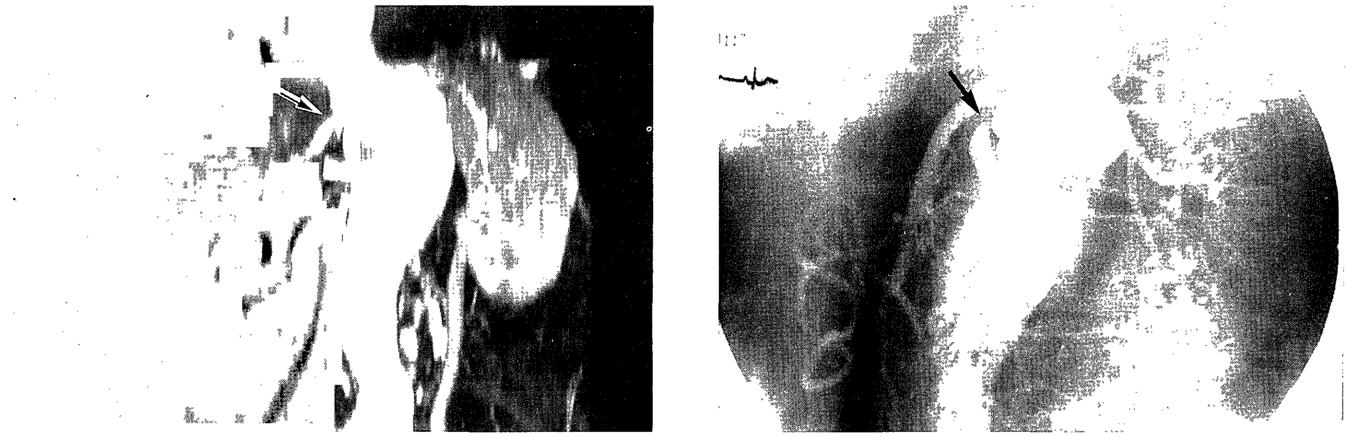
Fig. 3. Abdominal aortic aneurysm.
A Catheter angiogram shows the left accessory renal artery (arrows).
B The left accessory renal artery (arrows) is clearly depicted on MIP image.



A B

Fig. 4. Abdominal aortic aneurysm.
A A MIP image shows mild stenosis of the proximal segment of the right renal artery (arrow).
B Catheter angiogram confirms the presence of mild stenosis in the proximal segment of the right renal artery (arrow).

depicted IMAs. In 5 of the 7 patients, IMA reconstruction was successfully achieved during surgery. The sensitivity of CT angiography for the identification of the celiac arteries, SMAs, RAs, accessory renal arteries, IMAs were, if these arteries were included in the scan area, 100%, 100%, 100%, 71.4%, and 76.9% respectively.

CT angiography correctly evaluated the presence or absence and the degree of renal artery stenosis in 98 out of 110 RAs. Twelve other renal arterial stenoses were overestimated by CT angiography (Fig. 4) (Table. 4).

Forty-four of the 55 patients with AAA underwent surgery. At surgery, 38 aneurysms were found to be infrarenal, while the remaining 6 aneurysms were found to be juxta-/suprarenal and necessitated suprarenal aortic clamping. All of the 38 infrarenal aneurysms were correctly diagnosed as such with both catheter angiography and spiral CT angiography. Their proximal extent was correctly assessed with spiral CT angiography in all of the 6 juxta-/suprarenal aneurysms, while 3 of them were incorrectly diagnosed as infrarenal at catheter angiography (Fig. 5) (Table. 5). At surgery, 20 aneurysms did not involve the aortoiliac bifurcation and straight graft was used in these cases. The remaining 24 aneurysms involved the bifurcation or extended more distally. Twenty-two of the 24 aneurysms were correctly diagnosed by catheter angiography as involving the bifurcation or at least one of the common iliac arteries (Table. 5) and the remaining 2 aneurysms were incorrectly diagnosed as terminating above the bifurcation. Sensitivity and specificity of catheter angiography to detect bifurcation involvement was 91,7% and 100%, respectively. At CT angiography they were both 100%.

Aortic dissection; double barreled type (Table. 6, 7)

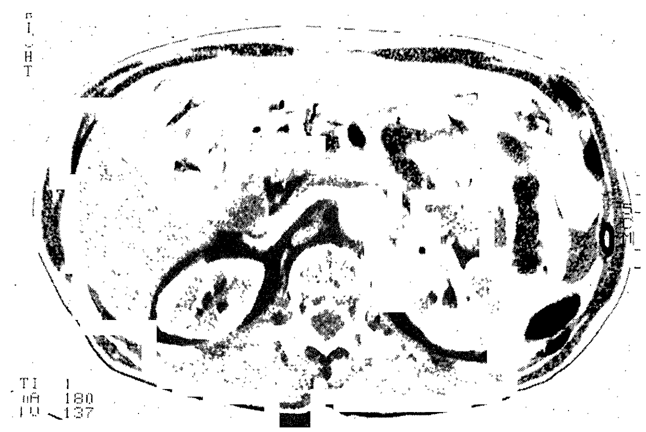
Of 15 patients with double barreled dissection, the dissection was diagnosed as Stanford type A in 3 patients and Stanford type B in 12 patients by catheter angiography. CT angiography correctly assessed Stanford classification in all of the 15 patients.

Catheter angiography demonstrated a total of 30 intimal tears in 15 patients including 15 entries, 11 reentries and 4 other communicating tears, while CT angiography delineated 23 of the intimal tears (76.7%) including 12 entries, 10 reentries, and 1 other communicating tears (Table 6) (Fig. 6).

Catheter angiography depicted a total of 70 major branches of the thoracic or abdominal aorta in 15 patients. Among these 70 major branches, 58 branches were diagnosed as originating from the true lumen, 5 branches from the false lumen and the remaining 7 branches from both lumens by catheter angiography. Fifty-seven of the 58 branches with true lumen origin were correctly diagnosed as originating from the true lumen by CT angiography, while the remaining one was incorrectly diagnosed as originating from the false lumen. All of the 5 branches with false lumen origin were correctly diagnosed by CT angiography also (Fig. 7). Six of the seven branches originating from both lumens were correctly diagnosed by CT angiography, while the remaining one was incorrectly diagnosed as originating from the false lumen.

Aortic dissection; thrombosed type

A total of 8 ULPs were depicted in 6 patients with thrombosed type dissection by catheter angiography. They were located at the superior aspect of the aortic



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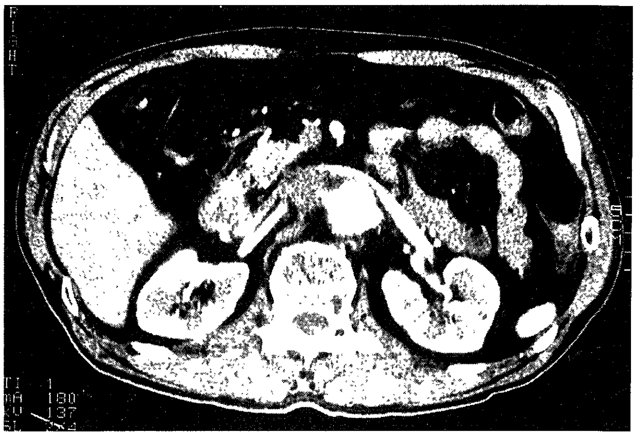

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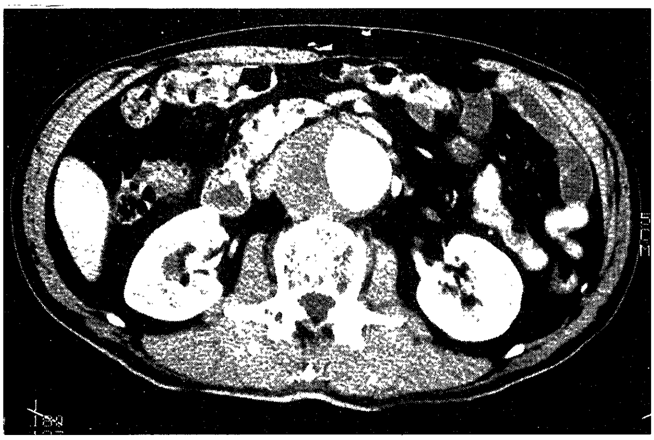

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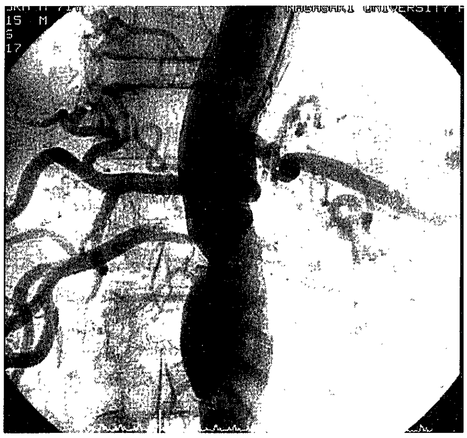


E

Fig. 5. Abdominal aortic aneurysm involving the renal artery.
A-C Contrast-enhanced CT shows an abdominal aneurysm which arises at the level of the origin of the right renal artery but it is difficult to determine exact relationship between the aneurysm and the renal artery solely on axial images.
D Multiplanar reconstruction reveals that mural thrombus attached to the lateral wall of aneurysm involves the right renal artery cranially.
E On catheter angiogram the aneurysm was interpreted to be located 2 cm away from the origin of the renal arteries due to the presence of the thrombus. At surgery, suprarenal aortic clamping was necessary for the repair of this juxtarenal aneurysm.

arch in 3 patients, and the proximal portion of the descending thoracic aorta in 5 patients. Spiral CT angiography also depicted all of them.

Discussion

Noninvasive modalities including US, conventional CT, and MRI are all used for the assessment of aortic pathologic conditions. However, none of these techniques singly provides all the information necessary for the preoperative evaluation, particularly on the extent of the abnormality, involvement of the major branches, and distal run-off[6,7]. Catheter angiography has been accepted as the gold standard to evaluate the abnormalities of aortic diseases. However, this technique is invasive and often requires a large amount of contrast material to provide multiprojection images of good quality.

Table 5. Correlation of CT angiography, catheter angiography and surgical findings in determining proximal and distal location of abdominal aortic aneurysm (n=44)

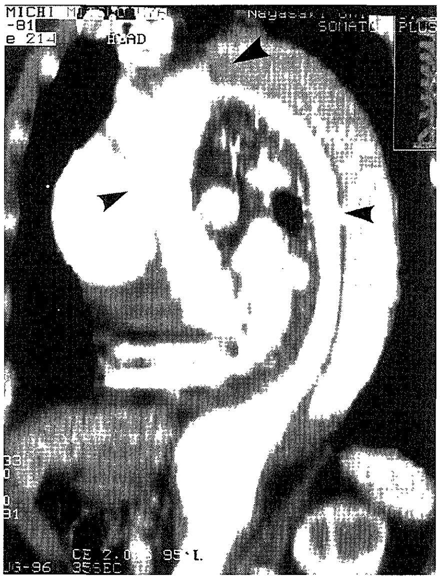
Location of AAA	CT angiography	Catheter angiography	No. of patients confirmed at surgery
Proximal extent			
infra renal	38	41	38
juxta/supra renal	6	3	6
Distal extent			
above bifurcation	20	22	20
beyond bifurcation	24	22	24

Table 6. Visualization of entry, reentry and communicating tears by CT angiography compared with catheter angiography (15 patients)

	No. of intimal tears depicted by CT angiography	No. of intimal tears depicted by catheter angiography
Entry	12	15
Reentry	10	11
Communicating tear	1	4
Total	23	30

Table 7. Identification of the lumen from which aortic branches originate by CT angiography compared with catheter angiography (n=15, 70 branches)

CT angiography	Catheter angiography True lumen	False lumen	True and false lumen	Total
True lumen	57	0	0	57
False lumen	1	5	1	7
True and false lumen	0	0	6	6
Total	58	5	7	70



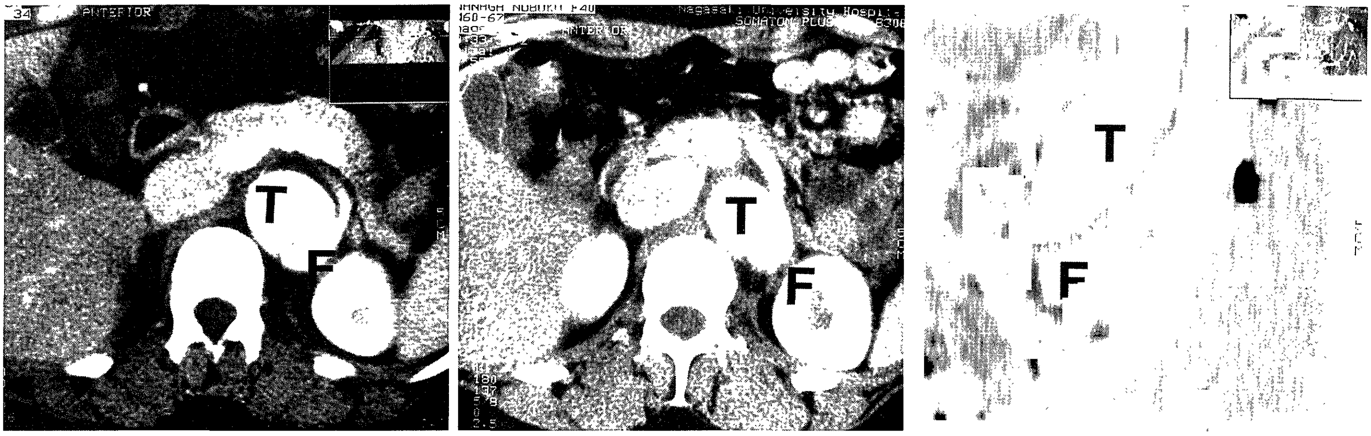
A

B

C

D

Fig. 6. Type A aortic dissection.
A Multiplanar reconstruction (oblique sagittal view) shows a type A dissection extending from distal aortic arch to the abdominal aorta, with intimal tears (arrow heads) located in the ascending aorta, the distal arch, and descending thoracic aorta.
B-C Catheter angiograms reveal intimal tears in similar locations.



A B C

Fig. 7. Type B aortic dissection.
A-B Contrast-enhanced CT obtained at the level of the pancreas shows the presence of an intimal flap within the abdominal aorta. The celiac artery is clearly shown to originate from the false lumen but it is difficult to determine the origin of the superior mesenteric artery solely on axial images.
C Sagittal reconstruction of the abdominal aorta reveals that the superior mesenteric artery originates from the true lumen. (T = true lumen, F = false lumen)

Spiral CT has recently been developed, based on the principle of continuous scanning during constant X-ray tube rotation and table movement. It is now possible to obtain very fast imaging of a large body volume with optimal vessel enhancement, in one breath holding with a single injection of contrast material. In addition, image processing provides three-dimensional images of the thoracic and abdominal aortas and their branches. We investigated whether CT angiography alone can provide all the information necessary for the diagnosis and treatment planning in AA and AD. No comprehensive study has so far been available in this regard to our knowledge.

The results of this study indicated that spiral CT angiography provides enough information necessary in both aortic aneurysm and aortic dissection. In aortic aneurysms, CT angiography provided more accurate information regarding the extent of the aneurysm than catheter angiography. The extent of aneurysm was underestimated by catheter angiography since contrast material only filled the patent lumen of the aneurysm having mural thrombus. Thus, CT angiography was better in determining whether the aneurysm involved the left subclavian artery in cases of thoracic aortic aneurysms, and renal artery and aortic bifurcation in cases of abdominal aortic aneurysms (Table 3 and 6). These data are similar to the data of previous comparative studies[6,8,9,10]. The relationship between aneurysm and the arch vessels was better displayed on angled sagittal MPR than on axial images alone. In some confusing cases in which the accurate assessment of the aneurysm extension was not possible by conventional axial and MIP images, the anatomic relationship of the aneurysm to the renal and iliac arteries was much better delineated by MPRs.

All of the celiac arteries, SMAs and RAs were clearly depicted by spiral CT angiography if these arteries were included in the scan area. Two of the 7 accessory renal arteries were not identified at spiral CT angiography probably because they were too small. It is controversial whether all of the accessory renal arteries arising from aneurysmal sac need to be implanted[11]. According to Couch et al. [12], re-implant was needed in only one accessory renal artery in a series of 110 aneurysm repairs.

The preoperative evaluation of IMA using imaging modalities is also crucial, because IMA should be reconstructed during surgery to protect the left colon if this artery arises from aneurysm[13]. The patency of IMA was demonstrated by both catheter and CT angiography in 20 patients, by catheter angiography alone in 6 patients, and by CT angiography alone in 7 patients. It can be stated that spiral CT angiography provides information equivalent to that of catheter angiography for determining the patency of IMAs.

The presence or absence of RA stenosis needs to be diagnosed preoperatively. If present, preoperative angioplasty or surgical revascularization is necessary[14]. In our study, spiral CT angiography detected all of the 8 cases with RA stenosis of moderate/severe (30-99%) or occlusion (100%). Previous authors also reported high accuracy in the detection of RA stenosis (more than 75%) with spiral CT angiography using 2-mm collimation and 1.5 pitch[9,10,11,15,16,17]. However, because of the limited z-axis coverage of 12 cm, they only assessed the proximal extent of aneurysms and RA stenosis. Iliac artery involvement is difficult to detect in their way. In spiral CT, a trade-off exists between collimation and z-axis coverage. Scanning with a section thickness of 1 mm would undoubtedly lead to higher accuracy in the display of small RAs. However it would result in limited z-axis coverage.

Three important aspects in the assessment of aortic dissection include the confirmation of dissection, the differentiation between type A and B dissections, and between double-barreled and thrombosed type dissections[12,18,19]. In addition, following information is necessary for planning aortic repair and estimating patient prognosis; the extension of dissection into the major aortic branches; the location of entry in double-barreled type dissection and ULP in thrombosed type dissection; the presence of thrombus in the false lumen; the presence of pericardial effusion; and the presence and severity of aortic insufficiency[20,21].

In this study, spiral CT findings of aortic dissection agreed with angiographic findings in the differentiation between type A and B dissections in all patients, and in the assessment of the extension of dissection into major branches in all but two branches. To our knowledge, there has been few reports in the English literature regarding the evaluation of branch involvement in the aortic dissection by spiral CT angiography. Sommer et al. described that sensitivity and specificity of detection of arch vessel involvement were 93%, 97% respectively in 15 patients of aortic dissection[18]. In our study, sensitivity of spiral CT angiography in the detection of arch vessel involvement was 100%. In the abdominal region, although angiographic evaluation was described in the literature[19], reports on spiral CT are not available. There were two major branches misdiagnosed at spiral CT angiography; they were both IMA. Spiral CT depicted all the ULPs in aortic dissection of thrombosed type. Seven of 30 (23%) intimal tears failed to show with spiral CT. However, the entry and reentry site, the most important information for surgical planning, were missed in only 15 % (4/26) of them. From the results of our study, we believe that spiral CT is equivalent to catheter angiography in the evaluation of aortic dissection, although further prospective studies of larger series of patients are needed to evaluate the ability to demonstrate intimal tears. MPR helps clarify the relationship between the intimal flap and adjacent major vessels and depict intimal tears, particularly in cases with redundant aorta and tortuous intimal flap.

CT angiography has limitation in the evaluation of aortic insufficiency and coronary artery involvement. Therefore, Stanford type A dissection should be evaluated preoperatively with catheter angiography.

The results of this study indicate that spiral CT angiography provides information necessary for surgical planning of aortic aneurysms including their location and extent and relationship to the major branches. In cases of aortic dissection, spiral CT angiography can provide information to select the method of treatment and to decide surgical planning. Our technique of CT angiography has limitations in visualizing the small structures including accessory renal and inferior mesenteric arteries, and in detection of RA stenosis, entry, reentry site and intimal tears. Recent technical advances, especially multidetector spiral CT[22], allow variable or narrower collimation and the use of increased pitch to achieve wide z-axis coverage. Using theses techniques, spiral CT will become an accurate method for the evaluation of aortic lesions discribed above with high resolution images. In the future, advanced spiral CT technique will be able to replace catheter angiography in evaluation of aortic aneurysm and Stanford type B dissection.

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