Emergency diagnosis of acute aortic dissection using magnetic resonance imaging

Akut aortik diseksiyonun tanısında manyetik rezonans görüntüleme

Ahmet Mesrur HALEFOĞLU

BACKGROUND

In our study, we aimed to demonstrate the utility of MR imaging in the emergency diagnosis of acute aortic dissection.

METHODS

Herein, 15 patients who were clinically suspected as having aortic dissection were assessed with both magnetic resonance imaging and 3D contrast enhanced MR angiography by means of a 1.5 tesla magnet.

RESULTS

Eleven patients were diagnosed as having aortic dissection by means of MRI. We were able to show the intimal flap in all of the aortic dissection patients and we also determined whether the dissection type was A or B. Although the dissections in three patients were found to be in proximal location (type A), eight patients showed a distally located (type B) dissection. All patients were subjected to angiography and 3 patients were operated. Our results were compared with the results of the angiography and operation, which were regarded as the gold standards.

CONCLUSION

Consequently, we can state that MR imaging may be used as an initial diagnostic modality for the patients with aortic dissection and this method can also serve as an useful method in the long term follow-up of these patients. It is a non-invasive and sensitive modality that is easy to perform and can be applied instead of other diagnostic modalities such as conventional angiography.

Key Words: Acute aortic syndrome; aortic dissection/diagnosis; magnetic resonance imaging/prognosis/treatment.

AMAÇ

Çalışmamızda, akut aortik diseksiyonun acil tanısında manyetik rezonans (MR) görüntülemenin yararlılığının ortaya konmasıdır.

GEREÇ VE YÖNTEM

Bu çalışmada klinik olarak aortik diseksiyon şüphesi olan 15 hastanın 1,5 tesla MR cihazı ile görüntüleri ve üç boyutlu kontrastlı MR anjiyografi görüntüleri elde edildi.

BULGULAR

Manyetik rezonans görüntüleme ile 11 hastaya aortik diseksiyon tanısı konuldu. Tüm olgularda intimal flebin gösterilmesi ve diseksiyonun A veya B tipinde olduğunun belirlenmesi mümkün oldu. Üç olguda diseksiyon proksimal yerleşim gösterdiği halde (tip A), diğer sekiz olguda distal yerleşim (tip B) söz konusuydu. Tüm olgulara anjiyografi yapıldı ve üç hasta ameliyat edildi. MR sonuçları altın standart olarak kabul edilen anjiyografi ve ameliyat sonuçları ile kıyaslandı.

SONUÇ

Sonuç olarak, MR görüntülemenin aortik diseksiyonlu hastalarda başlangıçta tanı amaçlı olarak ve bu hastaların uzun dönemli takiplerinde kullanılabilecek bir modalite olduğunu söyleyebiliriz. MR görüntüleme noninvaziv hassas bir yöntem olup, uygulanması kolaydır ve konvansiyonel anjiyografi gibi diğer tanısal yöntemlerin yerine kullanılabilir.

Anahtar Sözcükler: Akut aortik sendrom; aortik diseksiyon/tanı; manyetik rezonans görüntüleme/prognoz/tedavi.

Department of Radiology, Şişli Etfal Training and Research Hospital, Istanbul, Turkey.

Şişli Etfal Eğitim ve Araştırma Hastanesi Radyoloji Kliniği, İstanbul.

Correspondence *(İletişim)*: A. Mesrur Halefoğlu, M.D. Birlik Sok., Parksaray Apt., No: 17 / 4, Levent 34340 İstanbul, Turkey.
Tel: +90 - 212 - 231 22 09 Fax *(Faks)*: +90 - 212 - 241 50 15 e-mail *(e-posta)*:halefoglu@hotmail.com

The estimated incidence of aortic dissection is 5 to 30 cases per million people per year, depending on the prevalence of risk factors in the study populations.[1,2] It may be fatal without early diagnosis and appropriate medical, surgical or endovascular treatments. The presenting symptoms and signs are so myriad and nonspecific that the dissection may be overlooked initially in up to 40% of cases. In addition, the diagnosis is established postmortem in a substantial number of cases.[3] The most frequently used modalities to identify dissection and define the sites of origin and termination are computerized tomography (CT), transesophageal echocardiography (TEE) and magnetic resonance imaging (MRI).

In our study, we showed that magnetic resonance imaging, together with 3D contrast enhanced magnetic resonance angiography (MRA) can serve as an initial imaging modality in the early diagnosis of aortic dissection. It provides sufficient information for the management of this pathologic condition. Our aim was to show its potential utility in the early diagnosis of aortic dissection.

MATERIALS AND METHODS

Prior to the study, an Institutional Ethical Committee approval and informed patient consent were obtained. Fifteen patients who were clinically suspected as having aortic dissection were examined by magnetic resonance imaging. All of these patients had a history of hypertension and 7 of them had diabetes mellitus, hyperlipidemia and atherosclerosis. Patients were admitted to the hospital consecutively during a 2 year - period. Among them, 11 patients were diagnosed as having aortic dissection.

The most important issue in terms of management and lethality was to determine the extent of the dissection so that it could be classified as either type A or type B dissection according to the Stanford classification.

These 11 patients aged between 35 to 66 years. Eight of them were males and three of them were females. All of the patients were subjected to angiography and three patients were operated. Our results were compared with the results of the angiography and operations, which were regarded as the gold standard. The magnetic resonance imaging was performed by using a 1.5 tesla superconducting magnet (General electric, signa, Milwaukee,Wisconsin, USA).

After administration of 40 cc. gadolinium DTPA, axial and sagittal double inversion recovery images, axial spin echo T1 weighted images, axial fast spoiled gradient echo images and 3D fast spoiled gradient echo images were obtained. Additionally MIP (maximal intensity projection) images were performed.

RESULTS

In aortic dissection cases, MR imaging demonstrated the intimal flap and also characterized the type of dissection as being either type A or type B.

In our study, 11 patients were diagnosed as having aortic dissection. By using MRI and MR angiography, we were able to identify intimal flap definitely in 11/11 patients and also determined the extension of the flap in order to classify aortic dissection either type A or type B. Four cases of suspected aortic dissection were found to be negative on MRI examination. Following clinical and laboratory examinations, 2 cases were diagnosed as having acute myocardial infarction and the other 2 cases were considered as healthy without any pathology.

MR provided the differentiation between the true and false lumens, determined the extension of the dissection into the abdominal aorta distally or aortic branches proximally (Fig. 1).

Fig. 1. Type B dissection, dissection in the ascending aorta and descending aorta also extending into left carotid communis and left subclavian arteries, 3D contrast MR angiography, coronal image.

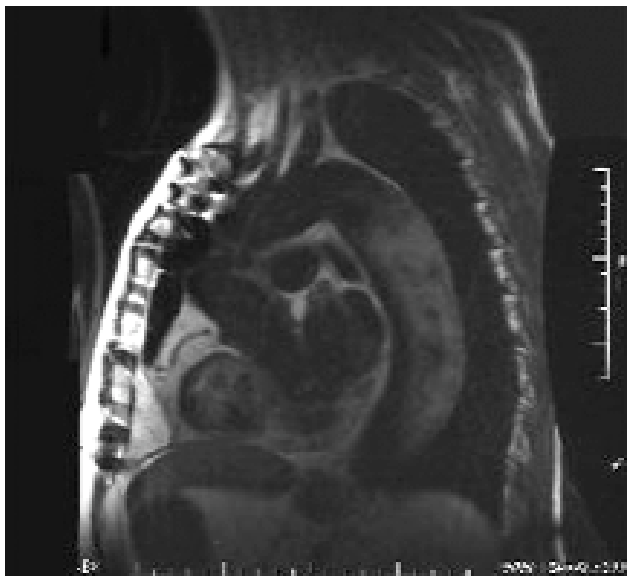

Fig. 2. Intimal flap is seen in the ascending and descending aorta; ascending aorta graft is seen just above the aortic root, type B aortic dissection, note the flow void in the true lumen and increased signal in the false lumen due to slow flow, sagittal double inversion recovery image.

The intimal flap was identified as a linear structure with flow void on one side in the true lumen and increased signal due to slow flow on the other side in the false lumen (Fig. 2).

In our patient population, three of the cases showed Type A dissection (Fig. 3) while the remaining 8 patients showed Type B dissection. The extent of the dissection to the ascending aorta, descending aorta, abdominal aorta, aortic branches (Fig. 4) or below the bifurcation level (Fig. 5) was clearly shown.

In Marfan syndrome patients, the dissection typically involves the ascending aorta and occurs in the third and fourth decades of life (Fig. 6).

Fig. 3. Intimal flap is seen involving both ascending and descending aorta, coronal gradient echo source image.

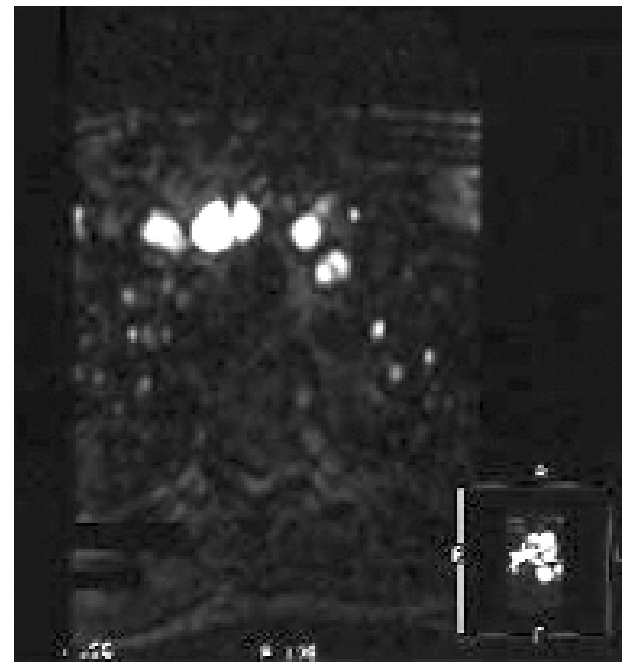

Fig. 4. Intimal flap is seen involving all the major branches of the aortic arch, 3D contrast MR angiography, axial image.

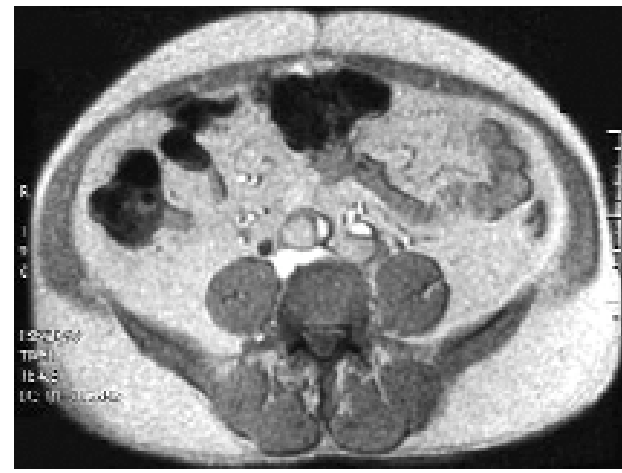

Fig. 5. Intimal flap is clearly seen in the both common iliac arteries. The flow void true lumen and thrombosed false lumen can be easily distinguished from each other. Fast spoiled gradient echo (flip angle 30) axial image.

Fig. 6. Aortic dissection involving ascending and descending aorta is seen in a Marfan syndrome patient (3D contrast MR angiography, coronal image).

Although the number of patients of our series was small, the sensitivity and specificity of the MRI together with MRA was found to be 100% in the diagnosis of aortic dissection. Following the diagnosis, all of the aortic dissection patients were evaluated by clinicians. In eight patients who had type B dissection, the main treatment was conservative. Therefore they initially received antihypertensive therapy to reduce the arterial blood pressure and left ventricular contractility. Also, they were given analgesics for pain control.

The other three patients who had type A aortic dissection were referred to thoracic surgery. In these patients, surgery was clearly the treatment of choice because of the dissection involving the ascending aorta; they were subjected to resection of the site of the tear, obliteration of the false lumen and replacement of the resected aortic segment with a synthetic graft.

DISCUSSION

The presence or absence of involvement of the ascending aorta determines the biological behavior and governs the lethality of dissections.[4,5]

In our study, MR clearly showed whether the dissection was type A[6] or type B.[7]

Anatomically, aortic dissection has been classified by two schemes. The DeBakey classification consists of the following three types:

1. both the ascending and the descending aorta are involved;

2. only the ascending aorta is involved;

3. only the descending aorta is involved.[8]

The Stanford classification consists of the following two types:

Type A, involving the ascending aorta regardless of the entry site location; and Type B, involving the aorta distal to the origin of the left subclavian artery.[9]

Type A dissection has high complication rates and may lead to life threatening rupture into the pericardium, causing tamponade and death. Type A dissection may also extend into the coronary arteries and occlude them, causing myocardial infarction. When dissection involves the aortic valve it may lead to aortic insufficiency and when it extends into the carotid arteries it may cause stroke. If unrecognized and untreated, fewer than 10% of patients with type A aortic dissection survive a year. Because of the high complication rate, surgical treatment is the preferred approach for type A dissection.

Type B dissections are frequently stable lesions, 60% were reported to have a benign course[10] and therefore conservative management is the preferred approach.

However, both type A and B aortic dissection may progress to a rupture with documented incidence of 7% with ascending aorta and with documented incidence of 3.6%[11] to 8%[10] with descending aorta involvements. It has been documented that the results of medical treatment in cases with type B dissection are comparable to those of surgery. Most of the patients succumb within the first three months[12] usually due to acute aortic insufficiency, major branch vessel occlusion or rupture into the pericardium, mediastinium or left hemithorax.

Imaging findings

The diagnosis of aortic dissection begins with clinical suspicion, which is the most crucial step in diagnosing this catastrophic disease. The next two important steps in the evaluation of patients with suspected aortic dissection are to confirm the presence

of dissection and to differentiate the proximal and distal dissections.

The diagnosis of a classic aortic dissection relies on the visualization of an intimomedial flap and blood flow within the true and false lumen.

Aortography has been used for many years as the modality of choice for demonstrating aortic dissection. It is effective in demonstrating the direct signs of dissection, the intimomedial flap and flow in the true and false lumens. Inaccuracy may arise in the presence of thrombosis of the false lumen or circumferential dissection. Erbel et al.[13] reported 88% sensitivity and 94% specificity for aortography in the diagnosis of aortic dissection. The need for injection of a contrast media and the invasive nature of the examination relegate catheter aortography to a secondary diagnostic modality. In recent years, aortography has been replaced by minimally invasive transesophageal echocardiography (TEE) and noninvasive cross-sectional imaging techniques; namely, CT and MRI for diagnosis of aortic dissection.

CT scanning is the most common initial diagnostic test because it is less invasive and allows rapid diagnosis in emergency situations.[1] The primary diagnostic criterion for diagnosis of aortic dissection by CT is the demonstration of two contrast-filled lumens separated by an intimal flap.[14] The sensitivity of CT ranges from 93% to 100% and specificity from 87% to 100%.[14,15]

In the assessment of the supra-aortic branches, spiral CT is superior to both TEE and MRI.[16] Inaccuracy may result from inadequate contrast opacification, nonvisualization of the intimal flap, artifacts extending across the aortic lumen that simulate an intimal flap, misinterpretation of adjacent vessels or prominent sinus of Valsalva as the flap, atelectasis, pleural thickening or thrombosis of the false lumen. Multidetector-row CT scanners offer more rapid image acquisition, variable section thickness, 3-dimensional rendering, diminished helical artifacts and smaller contrast requirements, overcoming many of the limitations discussed above.[17]

TEE is widely available, safe in experienced hands and can be performed quickly and easily at the bedside. These advantages make TEE ideal for use in most patients with aortic dissections, including relatively unstable patients. The examination can be performed soon after the patient presents to the emergency department and has a sensitivity of 95% to 98% and specificity of 63% to 96%.[13,18] The most important diagnostic finding of aortic dissection that can be seen on TEEs is the presence of an undulating intimal flap within the aortic lumen that differentiates a false lumen from a true lumen. In order to avoid a false-positive diagnosis, the intimal flap has to be identified in more than one view and it should have motion that is independent from that of the aortic wall. The possibility of aortic dissection is increased if an entry site, color Doppler flow and/or thrombus in the false lumen or aortic root dilatation are seen in addition to the intimal flap. Limitations are as following: the coronary arteries and the arch vessels may not be adequately visualized; extension into the visceral or iliac arteries may go undetected; there is a blind spot in the proximal aortic arch, and the quality of the study is operator dependent. Supplementing TEE findings with additional imaging studies may improve diagnostic accuracy, especially in cases in which TEE findings are considered to be probable for the presence of aortic dissection and the clinical suspicion of aortic dissection is high.[19]

MRI can serve as the initial imaging modality in clinically suspected aortic dissection cases and provides sufficient information in the management and follow-up of these patients. MRI advantages in the assessment of aortic dissection include multiplanar acquisition, lack of radiation and the potential without contrast injection need. The limitations of MRI include long imaging time, the need for patient cooperation to avoid motion-related image degradation and difficulty in monitoring acutely ill patients. Also, cardiac arrhythmia may prevent gating for adequate MRI. However, in some of the newest rapid acquisition MRI techniques, the acquisition window is less than a second, which may obviate the requirement for ECG triggering.

The sensitivity and specificity of MR imaging for diagnosis of aortic dissection has been reported to be between 95% and 100%.[20,21]

Typical strategies for aortic imaging with MR include black blood techniques, bright blood techniques and contrast enhanced MR angiography (MRA).

On SE sequences, the intimomedial flap is a linear structure of intermediate signal intensity dividing

the aortic lumen into two channels, both of which exhibit a flow void. The false lumen may contain intermediate signal content that can represent thrombus or slow blood flow. Intimal calcifications are not seen on MRI.

Gradient recalled echo (GRE) bright blood imaging and phase-contrast imaging are flow sensitive and can complement SE black blood imaging. The intimomedial flap on GRE images is visualized as a low intensity linear structure between high intensity flowing blood in the true and false channels. Because GRE is flow sensitive, it is very useful in distinguishing between slow flow, which would show a flow-related signal increase, and thrombus, which would have inherent low signal. Phase-contrast imaging can be used to obtain quantitative information, as it allows for assessment of the velocity and direction of flow.

The advantage of MRI over CT is its ability to provide functional information, such as valve regurgitation or left ventricular dysfunction. GRE cine acquisition is particularly useful in showing aortic insufficiency related to dissection.

Recently, contrast-enhanced 3D MRA has become a crucial part of aortic imaging protocol. The use of paramagnetic contrast agents provides a high signal to noise ratio with angiographic-like views of the aorta and with superior demonstration of involvement of branch vessel origins by dissection. For 3D visualization, MIP reconstructions are the methods of choice for contrast enhanced MRA. A 3D spoiled gradient-echo pulse sequence is typically used after bolus injection. Acquisition can be performed with or without breath-hold. However, it was shown that optimized, single-dose (0.1 mmol/kg) breath-hold gadolinium-enhanced 3D MRA was superior to double-dose (0.2 mmol/kg) nonbreath-hold 3D MRA for evaluation of thoracic aortic disease.[22] Excellent sensitivity (92%-96%) and specificity (100%) have been documented for contrast-enhanced MRA, both for acute and chronic aortic dissection.[23]

Also if intimointimal intussusception is suspected in a patient, MRI should be considered as one of the more reliable diagnostic tools for arriving at the correct diagnosis for this rare type of aortic dissection.[24]

However, in the evaluation of patients with acute aortic dissection, CT is selected mostly worldwide as the initial test, followed by TEE.[25] Although MRI is the most sensitive method for detecting aortic dissection, it is used as the first imaging modality for only a very small number of patients who present acutely since it is less widely available than CT and is harder to use with critically ill patients. But in the studies that compared MRI with TEE or CT scanning,[21,26] the sensitivity and specificity of MRI was higher among the patients with previous aortic disease. In addition, the MRI has the capability to perform the three-dimensional reconstruction of the images in any plane.

Soulen RL et al.[27] showed that MR imaging was superior to CT in the evaluation of postoperative patients because the artifact produced by valves precludes adequate evaluation of aortic root on CT scans, while producing only a small inferior field distortion, a "pseudo-ventricular septal defect" on MR images. The absence of radiation exposure is another significant advantage for the relatively young Marfan syndrome population, that requires serial studies. MR imaging is the modality of choice for evaluation and follow-up of patients with Marfan syndrome and offers an appropriate means of screening their kindred.

In their study, Shiga T et al.[28] systematically reviewed the diagnostic accuracy of TEE, MRI and helical CT in patients with suspected thoracic aortic dissection including a total of 1139 selected patients. Sensitivity, specificity and positive and negative odds ratios were pooled in a random-effects model. Pooled sensitivity (98%-100%) and specificity (95%-98%) were comparable between imaging techniques. The pooled positive odds ratio appeared to be higher for MRI (25.3) than for TEE (14.1) or helical CT (13.9). They concluded that all three imaging techniques, i.e., TEE, helical CT and MRI, yielded clinically reliable diagnostic values for confirming or ruling out thoracic aortic dissection.

In another study performed by De Cicco ML et al.,[29] 18 patients with suspected or known aortic dissection underwent in emergency conditions 1.5 tesla MRI with Steady-state sequence. The results obtained with this 2D- GE breath hold cardiac triggered imaging sequence were compared in terms of diagnostic accuracy and execution time with those of classical MRI examination (Black blood T 1, FSE T 2 and 3D- MRA) or multislice CT. The diagnostic accuracy of MRI both with Steady-state sequence

and the classical technique and multislice CT in the diagnosis of dissection or aneurysm was equal (100%), whereas execution time was 6, 25 and 6 minutes, respectively. They concluded that Steady-state MRI sequence provided a diagnosis of aortic dissection or aneurysmal dilation in a short time and may represent a valuable alternative to CT in emergency settings, especially in patients with reported contraindications to iodinated contrast media.

Fast imaging using Steady-state free precession is a new bright blood approach for evaluating the diseases of thoracic aorta.[30] This technique is well suited for evaluating aortic dissection and can also depict extraaortic manifestations, although its value in the detection of intramural hematomas and branch vessel involvement has not yet been established.[30]

In their study, Kunz PR et al.[31] demonstrated that sensitivity and specificity of black blood sequences compared with those of contrast-enhanced MRA in detecting intimal flaps were 87% and 94% for the thoracic aorta and 54% and 97% for the supraaortic branches, respectively. Contrast-enhanced MRA was subjectively rated as superior to black blood techniques for visualizing intimal flaps and yielded better overall image quality. They concluded that contrast-enhanced MRA of the thoracic and abdominal aorta can provide all the information that the referring clinicians need on the morphology of aortic dissection and can be regarded as the standard MRI sequence for depicting intimal flaps and assessing branch vessel involvement.

Due to the reported sensitivity and specificity of MRI for diagnosis of aortic dissection as being between 95% and 100%,[20,21] it should be used as the first imaging modality. MRI has the advantage of eliminating the need for potential nephrotoxic contrast and ionizing radiation and thereby offers an advantage over CT. Another major advantage of MRI over CT is the ability to obtain sagittal and coronal images without degradation in spatial resolution.

MRI exhibits a big advantage over TEE, if they are compared with each other. MRI does not have TEE limitations. These limitations are depending on operator's skills and blind areas in the distal ascending aorta and the proximal transverse arch, which are obscured by air-containing trachea and left main bronchus.

MRI has some limitations and risks for patients that can preclude examination. These are long imaging time, limited scanner availability, noncompatible life support equipment, severe patient claustrophobia and the presence of ferromagnetic implants or pacemakers.

Aortic dissection may become rapidly fatal if left undiagnosed and untreated. CT scanning, MRI and TEE are all fairly accurate modalities that are used to diagnose aortic dissection, but each is fraught with certain limitations. The choice of the diagnostic modality depends, to a great extent, on the availability and expertise at the given institution.

Currently, MRI is often considered for the aortic evaluation in the following circumstances:

1. for elective evaluation of the less acute patients,

2. for differentiation of an intramural hematoma and a false lumen in aortic dissection,

3. for patients with allergy to iodinated contrast or those with renal failure,

4. for patients with inflammatory disease of aorta and,

5. for post-operative follow-up.

The potential for aneurysm formation, progressive dissection, and redissection of the remainder of the aorta demands careful monitoring of long-term survivors.[32,33] Regardless of the initial management strategy, patients should undergo periodical surveillance imaging by MRI or CT for every 6 to 12 months to monitor the diameter of the aorta, the extent of dissection and the status of the repair that might require additional intervention. The most common cause of death in long-term survivors of aortic dissections is the rupture of the aorta due to a subsequent dissection or aneurysm formation.

CONCLUSION

In our study, we have demonstrated clearly that magnetic resonance imaging, together with 3D contrast enhanced MR angiography is a very sensitive, useful, non-invasive and accurate modality for the diagnosis of the aortic dissection and provides a substantial amount of priceless information.

We have been able to show the aortic dissection with its extension to other vessels and also have been able to classify it as either type A or type B.

At the present time, a high clinical suspicion followed by a prompt imaging modality, is the most prudent approach to the diagnosis of acute aortic dissection.

We can suggest that MR imaging with angiography could be the first imaging modality both for the early diagnosis of aortic dissection or the long term follow-up of these patients.

REFERENCES

1. Hagan PG, Nienaber CA, Isselbacher EM, Bruckman D, Karavite DJ, Russman PL, et al. The International Registry of Acute Aortic Dissection (IRAD): new insights into an old disease. JAMA 2000;283:897-903.
2. Eisenberg MJ, Rice SA, Paraschos A, Caputo GR, Schiller NB. The clinical spectrum of patients with aneurysms of the ascending aorta. Am Heart J 1993;125(5 Pt 1):1380-5.
3. Khan IA, Nair CK. Clinical, diagnostic, and management perspectives of aortic dissection. Chest. 2002;122:311-28.
4. Miller DC, Stinson EB, Oyer PE, Rossiter SJ, Reitz BA, Griepp RB, et al. Operative treatment of aortic dissections. Experience with 125 patients over a sixteen-year period. J Thorac Cardiovasc Surg 1979;78:365-82.
5. De Bakey ME, Cooley DA, Creech O Jr. Surgical considerations of dissecting aneurysm of the aorta. Ann Surg 1955;142:586-610.
6. Hayashi K, Meaney TF, Zelch JV, Tarar R. Aortographic analysis of aortic dissection. Am J Roentgenol Radium Ther Nucl Med 1974;122:769-82.
7. Wheat MW Jr. Acute dissecting aneurysms of the aorta: diagnosis and treatment--1979. Am Heart J 1980;99:373-87.
8. DeBakey ME, Henly WS, Cooley DA, Morris GC Jr, Crawford ES, Beall AC Jr. Surgical management of dissecting aneurysms of the aorta. J Thorac Cardiovasc Surg 1965;49:130-49.
9. Daily PO, Trueblood HW, Stinson EB, Wuerflein RD, Shumway NE. Management of acute aortic dissections. Ann Thorac Surg 1970;10:237-47.
10. Elefteriades JA, Lovoulos CJ, Coady MA, Tellides G, Kopf GS, Rizzo JA. Management of descending aortic dissection. Ann Thorac Surg 1999;67:2002-5; discussion 2014-9.
11. Coady MA, Rizzo JA, Hammond GL, Pierce JG, Kopf GS, Elefteriades JA. Penetrating ulcer of the thoracic aorta: what is it? How do we recognize it? How do we manage it? J Vasc Surg 1998;27:1006-15; discussion 1015-6.
12. Meszaros I, Morocz J, Szlavi J, Schmidt J, Tornoci L, Nagy L, et al. Epidemiology and clinicopathology of aortic dissection. Chest 2000;117:1271-8.
13. Erbel R, Engberding R, Daniel W, Roelandt J, Visser C, Rennollet H. Echocardiography in diagnosis of aortic dissection. Lancet 1989;1:457-61.
14. Cigarroa JE, Isselbacher EM, DeSanctis RW, Eagle KA. Diagnostic imaging in the evaluation of suspected aortic dissection. Old standards and new directions. N Engl J Med 1993;328:35-43.
15. Nienaber CA, von Kodolitsch Y, Nicolas V, Siglow V, Piepho A, Brockhoff C, et al. The diagnosis of thoracic aortic dissection by noninvasive imaging procedures. N Engl J Med 1993;328:1-9.
16. Sommer T, Fehske W, Holzknecht N, Smekal AV, Keller E, Lutterbey G, et al. Aortic dissection: a comparative study of diagnosis with spiral CT, multiplanar transesophageal echocardiography, and MR imaging. Radiology 1996;199:347-52.
17. Rubin GD. MDCT imaging of the aorta and peripheral vessels. Eur J Radiol 2003;45 Suppl 1:S42-9.
18. Keren A, Kim CB, Hu BS, Eyngorina I, Billingham ME, Mitchell RS, et al. Accuracy of biplane and multiplane transesophageal echocardiography in diagnosis of typical acute aortic dissection and intramural hematoma. J Am Coll Cardiol 1996;28:627-36.
19. Penco M, Paparoni S, Dagianti A, Fusilli C, Vitarelli A, De Remigis F, et al. Usefulness of transesophageal echocardiography in the assessment of aortic dissection. Am J Cardiol 2000;86:53G-56G.
20. Tomiguchi S, Morishita S, Nakashima R, Hara M, Oyama Y, Kojima A, et al. Usefulness of turbo-FLASH dynamic MR imaging of dissecting aneurysms of the thoracic aorta. Cardiovasc Intervent Radiol 1994;17:17-21.
21. Mendelson DS, Apter S, Mitty HA, Gendal ES, Janus CL, Ergin MA, et al. Residual dissection of the thoracic aorta after repair: MRI-angiographic correlation. Comput Med Imaging Graph 1991;15:31-5.
22. Krinsky GA, Reuss PM, Lee VS, Carbognin G, Rofsky NM. Thoracic aorta: comparison of single-dose breath-hold and double-dose non-breath-hold gadolinium-enhanced three-dimensional MR angiography. AJR Am J Roentgenol 1999;173:145-50.
23. Krinsky GA, Rofsky NM, DeCorato DR, Weinreb JC, Earls JP, Flyer MA, et al. Thoracic aorta: comparison of gadolinium-enhanced three-dimensional MR angiography with conventional MR imaging. Radiology 1997;202:183-93.
24. Fan ZM, Zhang ZQ, Ma XH, Guo X. Acute aortic dissection with intimal intussusception: MRI appearances. AJR Am J Roentgenol 2006;186:841-3.
25. Moore AG, Eagle KA, Bruckman D, Moon BS, Malouf JF, Fattori R, et al. Choice of computed tomography, transesophageal echocardiography, magnetic resonance imaging, and aortography in acute aortic dissection: International Registry of Acute Aortic Dissection (IRAD). Am J Cardiol 2002;89:1235-8.
26. Rofsky NM, Weinreb JC, Grossi EA, Galloway AC, Libes RB, Colvin SB, et al. Aortic aneurysm and dissection: normal MR imaging and CT findings after surgical repair with the continuous-suture graft-inclusion technique. Radiology 1993;186:195-201.

27. Soulen RL, Fishman EK, Pyeritz RE, Zerhouni EA, Pessar ML. Marfan syndrome: evaluation with MR imaging versus CT. Radiology 1987;165:697-701.
28. Shiga T, Wajima Z, Apfel CC, Inoue T, Ohe Y. Diagnostic accuracy of transesophageal echocardiography, helical computed tomography, and magnetic resonance imaging for suspected thoracic aortic dissection: systematic review and meta-analysis. Arch Intern Med 2006;166:1350-6.
29. De Cicco ML, Andreoli C, Casciani E, Polettini E, Gualdi GF. Steady state evaluation of aortic dissections: A feasibility study. Radiol Med 2005;110:523-31.
30. Pereles FS, McCarthy RM, Baskaran V, Carr JC, Kapoor V, Krupinski EA, et al. Thoracic aortic dissection and aneurysm: evaluation with nonenhanced true FISP MR angiography in less than 4 minutes. Radiology 2002;223:270-4.
31. Kunz RP, Oberholzer K, Kuroczynski W, Horstick G, Krummenauer F, Thelen M, et al. Assessment of chronic aortic dissection: contribution of different ECG-gated breath-hold MRI techniques. AJR Am J Roentgenol 2004;182:1319-26.
32. Pansini S, Gagliardotto PV, Pompei E, Parisi F, Bardi G, Castenetto E, et al. Early and late risk factors in surgical treatment of acute type A aortic dissection. Ann Thorac Surg 1998;66:779-84.
33. Fann JI, Smith JA, Miller DC, Mitchell RS, Moore KA, Grunkemeier G, et al. Surgical management of aortic dissection during a 30-year period. Circulation 1995;92(9 Suppl):II113-21.