

# Usefulness of ultrasound in the management of aortic dissection

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Aortic dissection is an acute large vessel disease characterized by sudden onset, rapid disease progression and high mortality. Color doppler ultrasound analyzed the morphological and hemodynamic status of aortic branches before and after aortic dissection surgery, including carotid, subclavian, renal, celiac, superior mesenteric and iliac arteries. Transthoracic echocardiography, vascular ultrasound, transesophageal echocardiography, intravascular ultrasound and contrast-enhanced ultrasonography are complementary to aortic multi-slice spiral computed tomography angiography for diagnosis, treatment and prognostic evaluation.

## Keywords

Aortic dissection; ultrasound; echocardiography

## 1. Introduction

Aortic dissection (AD) is an acute large vessel disease caused by elastic fiber degeneration, tearing of the inner membrane, and sudden dissection of the vessel wall as blood enters this potential space. Common etiologies include chronic hypertension, Marfan syndrome, and congenital valve disease. AD has a rapid onset and disease progression. Without timely treatment, the mortality rate is as high as 1% per hour within 48 hours (Baloria et al., 2013). Therefore, timely diagnosis and appropriate surgical intervention are critical (Svensson et al., 2008; Olsson, 2006; Eggebrecht et al., 2005; Kitai et al., 2009). The Stanford classification is a commonly used framework for clinical and surgical management as well as prognostic information (Sun et al., 2005). The study was approved by the Beijing Anzhen Hospital medical ethics committees and adhered to the principles of the Declaration of Helsinki.

## 2. Criteria for detailed classification

Stanford Type A lesions involve the aortic root and include Subtypes A1, A2 and A3. Type A1 have normal aortic sinuses, normal sinus junctions, and avulsion of only one aortic valve junction without obvious insufficiency. Type A2 have minor sinus involvement and a sinus diameter < 3.5 cm. Interlayer involvement of a coronary artery branch leads to partial or total avulsion of the in-

tima of the opening and avulsion of one or two aortic valvular junction with slight to moderate aortic regurgitation. Type A3 have severe sinus involvement and a sinus diameter of 3.5 ~ 5.0 cm. The junctional structure of the sinus canal is damaged by endomembrane tearing and there is severe aortic regurgitation. For type A lesions, aortic arch involvement is further divided into types C and S. Type C includes one of the following: a primary tear in or distal to the aortic arch and retrograde dissection to the ascending aorta or proximal arch, aneurysms in or distal to the arch (diameter > 5.0 cm), dissection of the anterior brachiocephalic artery, and/or Marfan syndrome. Type S refers to a primary tear in the ascending aorta without any type C features.

Stanford Type B lesions are divided into B1, B2 and B3 according to the location of aortic dilation ( $\geq 4.0$  cm). Type B1 are localized to the proximal descending aorta with minimal proximal expansion. Type B2 are characterized by expansion of the entire descending thoracic aorta with minimal abdominal aortic involvement. Type B3 have expansion of both the thoracic descending aorta and abdominal aorta. Type B lesions are further subdivided based on left subclavian and distal aortic arch involvement into types C and S. Type C refers to intimal tear involving the left subclavian artery and the distal aortic arch. Type S refers to lesions distal to the aortic arch with a tear at the distal opening of the left subclavian artery.

## 3. Conventional ultrasonography

### 3.1 Transthoracic echocardiography and vascular ultrasound

Digital subtraction angiography (DSA) is the gold standard for evaluating AD but is invasive and has limited clinical utility. Amongst imaging modalities, transesophageal echocardiography has the highest diagnostic specificity, but is limited as a routine clinical diagnostic tool. Aortic multi-slice spiral computed tomography angiography (CTA) and magnetic resonance imaging (MRI) cannot be used on patients who are allergic to contrast agents or, for MRI, have metal implants in their bodies. For these reasons, transthoracic echocardiography (TTE) and conventional ultrasound have become indispensable tools for rapid and conve-

nient clinical evaluation of AD. TTE permits adequate assessment of several aortic segments, particularly the aortic root and proximal ascending aorta and, in most cases, the aortic arch, proximal descending aorta and abdominal aorta (Evangelista et al., 2018). TTE can clearly visualize internal flaps, intimal tears, aortic arch damage, coronary artery damage and the width of the aortic sinus and sinus junction in most patients with AD. TTE is most useful when the flap is located in the aortic root. The diagnostic accuracy rate of ultrasound for A1S, A2S and A3S was 100%, but subtype B3C was frequently missed, and the accuracy of Aortic CTA for A1S, A1C and all B subtypes was 100%, but A2S and A2C were problematic. As such, combining ultrasound and CTA improves diagnostic accuracy.

Conventional ultrasound (TTE and Vascular ultrasound) has a wide scanning range, can easily be performed at multiple levels to evaluate the ascending aorta, aortic arch, thoracic aorta, and abdominal aorta, is a common imaging method for the clinical diagnosis of AD. It can be used for bedside examination, is convenient for repeated examination, and can directly and dynamically observe the motion of internal flaps. Ultrasonography showed that the strong echo inside the aortic cavity divided the aortic cavity into true and false lumens, in which the true cavity expanded during systolic and compressed during diastolic, while the false lumens were opposite. Color doppler ultrasound can image abnormal blood flow in the true and false lumen of aortic dissection. The velocity of the true cavity is relatively fast while that of the false lumen is slow and once thrombosis occurs in the false lumen the blood flow signal disappears. Color doppler ultrasound can also identify the position of partial aortic rupture, which is of clinically utility in deciding the appropriate surgical intervention.

TTE is of high value in determining aortic valvular dysfunction, pericardial tamponade, or wall motion abnormalities (Nienaber, 2013). However, there are still limitations in the clinical application of ultrasonography due in part to variability introduced by the anatomic location of the lesion and physical factors such as emphysema and intestinal gas. As such, depending on the specific circumstances, the technique can be prone to misdiagnosis and missed diagnosis.

#### 4. Transesophageal echocardiography(TEE)

TEE scans the heart and large vessels from the back of the left atrium, avoiding reflection and interference from the chest wall, lungs, and other structures, ensuring excellent penetration of the sound beam and maximizing signal clarity of lesions. The diagnostic value of AD has been confirmed by more and more scholars and clinical workers. Multiple studies showed that the sensitivity of TEE for diagnosing AD was 86% ~ 100%, the specificity could be up to 77% ~ 100%. However, since patients with AD are in critical condition and TEE is a semi-invasive procedure, TEE evaluation of AD patients is generally performed under anesthesia.

TEE imaging technologies can be broadly divided into 2D- and 3D-TEE. With a good acoustic window, 2D-TEE can clearly visualize clinically relevant information in AD patients. This includes: the aortic ring and degree of disc leaf damage, the aortic sinus and coronary artery involvement, the number and position of tears and again entrance, mezzanine involving range, ventricular wall motion, pericardial effusion, the compression effect of the aorta on the surrounding tissue, and hemodynamic changes. This greatly enhances the ability of ultrasound to enable an accurate and

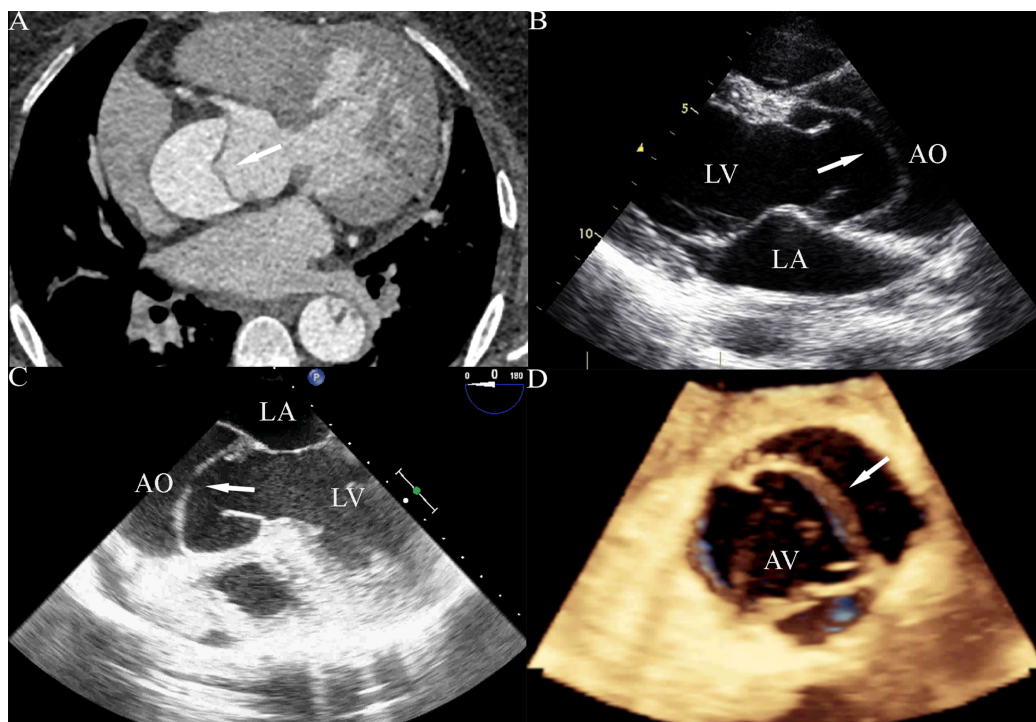


Figure 1. Type A aortic dissection of a 53-year-old woman diagnosed by Aortic CTA (figureA), TTE (figureB), TEE (figureC) and 3D-TEE (figureD). Arrows show the intimal flap in the aortic root. Ao, Aorta; LA, left atrium; LV, left ventricle; AV, aortic valve.

detailed AD classification and thus to guide the formulation and implementation of an effective treatment plan. Importantly, following surgical intervention for aortic root involvement 2D-TEE was also able to immediately evaluate whether there was coronary artery anastomotic leakage after, coronary arterial perfusion, patency of aort-right atrial shunt, recovery of ventricular wall movement, and cardiac systolic function. It can also be helpful for the selection of the type of stent and the positioning of its release during endovascular repair of patients with Stanford type B lesions, and evaluate the curative effect of the surgery immediately. However, the upper segment of ascending aorta and the arch of aorta are separated from the esophagus by gas-bearing trachea, and TEE is difficult to show the involvement of some of the arch vessels at the same time, thus affecting TEE's ability to classify AD.

3D-TEE has both 2D-TEE diagnostic capacity and the ability to perform high resolution 3D reconstructions. This capability provides a significant advantage when evaluating some features of AD lesions, such as clearly visualizing the stripped lining and three-dimensional shape of "spiral", "C", and "sleeve" lesions. Real-time 3D-TEE (RT-3D-TEE) can display internal flaps during regular exercise and in real time with the cardiac cycle. Since most AD tears are elliptical or irregular in shape, internal flaps appear as fracture-like lines when visualized by 2D-TEE while 3D-TEE can reconstruct the true three-dimensional shape of the tear opening, which is helpful for its accurate measurement. RT-3D-TEE also allows observation of morphological changes in the tear in real-time with the cardiac cycle and full-volume color blood flow imaging adds the ability to monitor blood stream bundles passing through the entry tears. 3D-TEE is also conducive to dynamic follow-up after reconstruction and visualization of the postoperative shape of the persistent false lumen. Evangelistal et al (2011) analyzed 2D-TEE images and 3D-TEE images and CT images from twenty six patients diagnosed with chronic AD. The results showed that 3D-TEE allowed better visualization of AD with spiral avulsion of the internal flaps than 2D-TEE. Additionally, 3D-TEE measurements were significantly better correlated with actual tear characteristics than that of 2D-TEE ( $r = 0.96$  and  $0.87$ , respectively,  $p < 0.001$ ), which often underestimated the size of the tear.

The sensitivity and specificity of each imaging technique for the diagnosis of aortic dissection were compared as shown in [Table 1](#). A case of type A aortic dissection diagnosed by Aortic CTA, TTE, TEE, 3D-TEE in [Fig. 1](#).

## 5. Intravascular ultrasound (IVUS)

The internal flap of AD is characterized by a pulsating hyperechoic structure in IVUS imaging and is connected with the hyperechoic inner layer of the true lumen. Identification of the true and false lumens is based on the three-layer ultrasonic structure of the external wall of the true lumen, the single-layer ultrasonic structure of the external wall of the false lumen, and the characteristic angle at the junction of the outer wall of the true and false lumens. IVUS can clearly display two-dimensional cross-sectional images of the anatomical structures from the aortic root to the bifurcation of iliac vessels, allowing comprehensive evaluation of AD aneurysm. It is superior to conventional diagnostic methods in its ability to clarify the relationship between the visceral artery and the true and false

lumen and the causes of ischemia of the visceral artery. IVUS can diagnose the cause of ischemia of visceral artery such as static stenosis and dynamic stenosis ([Jiang et al., 2003a,b](#)). IVUS can verify the choice of stent size and accurately release and evaluate the efficacy of the stent in the Stanford B AD endovascular stent implantation. IVUS can replace the angiography based on contrast agent to guide the repair of aortic intracavitary covered stent and avoid the deterioration of renal function in patients with renal insufficiency caused by contrast agent ([Koschyk et al., 2000](#)). IVUS can accurately locate the puncture site and avoid the occurrence of complications such as arterial wall injury during balloon fenestration in AD patients. However, IVUS could not show the aortic ring, the involvement of the leaflet and the motion of the ventricle, and could not assess the degree of aortic regurgitation and cardiac function.

## 6. Contrast-enhanced ultrasonography (CEUS)

Vascular remodeling after AD is usually assessed by multi-slice spiral CT. However, CT imaging is limited to the anatomical structure and cannot assess hemodynamics. Recently, color Doppler ultrasound and improved ultrasound contrast agent has allowed detection of the true lumen of spiral AD, blood flow through the crevasse, and eddy current injection while collecting hemodynamic parameters. This imaging modality also allows repeated observations and is advantageous when observing AD after interventional abdominal vascular remodeling ([Cheng et al., 2010](#)). With improvements in contrast agents, the clinical applications of ultrasound angiography continue to rapidly expand. Sonovine is a safe microbubble suspension preparation which can quickly be administered through the lungs during respiration, is metabolized by the liver, and can be used safely in patients with renal failure ([Clevert et al., 2008](#); [Evangelistal et al., 2010](#)). [Clevert et al \(2007\)](#) applied contrast-enhanced ultrasound to examine abdominal aortic aneurysm, including tumor wall and path as well as blood flow in the true and false cavities. Subsequently, [Clevert et al](#) used color Doppler ultrasound combined with CEUS to observe abdominal aortic aneurysm, which improved the accuracy of diagnosis. Therefore, patients with renal injury, severe atopy, or other contraindications to Aortic multi-slice spiral CT angiography examination can be offered an alternative.

## 7. The main branch of aortic dissection was evaluated by ultrasonography

### 7.1. Carotid artery

Fractional flow reserve is a pressure derived, lesion-specific, physiological index to determine the hemodynamic severity of intracoronary lesions. Stanford type A lesions are most likely to involve the brachiocephalic artery, resulting in carotid dissection and affecting carotid blood flow. There is limited data regarding carotid artery involvement in AD and its influence on cerebral blood supply ([Lucas et al., 1998](#); [Sukockiene et al., 2016](#)). [Lumsden S et al](#) report a case of spontaneous recanalization of a traumatic carotid dissection in which carotid ultrasound and transcranial color-coded duplex ultrasound (TCCD) were used ([Lumsden et al., 2017](#)). [Benninger DH et al](#) presented ultrasound assess-

Table 1. Comparison of imaging techniques for the diagnosis of AD

Source	Number of patients	Sensitivity	Specificity	Reference standard
TTE				
Kodolitsch et al., 1999	86	67	70	Surgery, autopsy, and angiography
Panchavinnin et al., 1990	16	91	100	Surgery angiography
Khandheria et al., 1989	67	79	78	Surgery
Dubourg et al., 1988	26	87.5	100	Surgery
TEE				
Mishra et al., 2005	24	100	92	Surgery
Pepi et al., 2000	58	100	100	Surgery, and CT, MRI
Nishino, 1996	15	86	75	Surgery and histologram
Sommer et al., 1996	49	100	94	Surgery, autopsy, and angiography
Evangelistal et al., 1996	132	99	100	Surgery, MRI and necropsy
Keren et al., 1996	112	98	95	CT, MRI, Surgery, and autopsy
Laissy et al., 1995	31	86	94	Angiography and Surgery
Chirillo et al., 1994	70	98	97	Surgery
Nienaber, 1993	70	98	77	Angiography, Surgery and autopsy
Simon et al., 1992	32	100	100	Surgery
Ballal et al., 1991	61	97	100	Aortography, surgery, or autopsy
CTA				
Mishra et al., 2005	24	100	92	Surgery
Yoshida et al., 2003	45	100	100	Surgery
Kodolitsch et al., 1999	86	79	87	Surgery, autopsy, and angiography
Sommer et al., 1996	49	100	100	Surgery, autopsy, and angiography
Zeman et al., 1995	23	100	92	Surgery or other imaging tests
MRI				
Silverman et al., 2000	78	100	100	Operative findings
Sommer et al., 1996	49	100	94	Surgery, autopsy, and angiography
Panting et al., 1995	50	96	100	Surgery and postmortem examination
Laissy et al., 1995	31	93	94	Angiography and Surgery
Nienaber, 1993	105	98	98	Angiography, Surgery and autopsy
Fruehwald et al., 1989	25	100	100	Angiography, CT, and echocardiography
Erbel et al., 1989	164	83	100	Surgery, autopsy, and Angiography
Kersting-Sommerhoff, 1988	54	91	100	Surgery, angiograph and CT

ment of spontaneous dissection of the carotid and vertebral arteries which discussed typical ultrasound findings and pitfalls in the acute AD, detection of microembolic signals, and recanalization (Benninger et al., 2005). Therefore, extracranial ultrasound and TCCD are useful for monitoring patient progress in cases of spontaneous recanalization following carotid artery dissection.

### 7.2. Renal artery

Color Doppler ultrasonography is the best noninvasive method for the diagnosis and monitoring of renal arterial blood supply in patients with abdominal AD. Acute kidney injury (AKI) is an independent risk factor for mortality after surgical intervention for AD and requires early intervention (Ren et al., 2015; Sasabuchi et al., 2016). Eggebrecht H et al analyzed data of 97 AD patients who underwent thoracic aortic stent-graft placement. Chronic kidney disease was present in 45% of patients preoperatively. Postprocedural AKI occurred in 33 patients (34%), and 3 required dialysis (Eggebrecht et al., 2006). Wu et al reported on hemodynamic

indices in the interlobular arteries of Stanford type A patients at different time points pre- and post-operatively (Wu et al., 2017). They found there was a statistically significant differences in end Diastolic Velocity, pulsatility index, and resistance index in patients with AKI compared to those without at 6 hours and 24 hours post-surgery. Importantly, postoperative renal interlobar artery resistance (DRRI) predicted AKI earlier than serum creatinine and the most useful timepoint was six hour after surgery.

### 7.3. Celiac axis and superior mesenteric artery

From proximal to distal, the abdominal aorta supplies the celiac axis, superior mesenteric artery, bilateral renal arteries, inferior mesenteric artery and other visceral branch arteries. Visceral ischemia caused by dissection of the celiac axis and/or superior mesenteric artery is a serious complication of AD and can be identified with emergent bedside vascular ultrasound (Davis and Kendall, 2013; Bret et al., 1987). Most important of all, celiac and superior mesenteric arteries were open to the false lumen in AD



patients, resulting in gastric and intestinal ischemia and mucosal necrosis leading to gastric and intestinal bleeding. Hashidomi H et al performed endovascular stent placement in the acute phase of superior mesenteric artery dissection without any preceding medical therapy and obtained a successful outcome. Intravascular ultrasound guidance was useful for confirming the location of the guidewire in the true lumen (Hashidomi and Saito, 2011).

## 8. Current situation

At present, the diagnosis and evaluation of AD relies heavily on multi-slice spiral CT, which has high anatomical resolution, short detection times, powerful image post-processing, and image quality that is minimally impacted by external factors. The IRAD Registry (JAMA) reported CT used in 61.1% and ultrasound used in 32.7% of AD cases (Hagan et al., 2000). However, Aortic CTA contrast agent can be nephrotoxic and only allows visualization of the lesion structure and morphology. Ultrasound captures hemodynamic information (such as true and false lumen pressures and blood flow characteristics) and, when TTE and abdominal ultrasound are combined, can image both the aortic arch and the abdominal aorta. It can provide real time information without contrast agent and without radioactivity. Bedside monitoring eliminates the need for patient transportation and reduces the risks associated with moving critically-ill patients within the hospital. Furthermore, TTE allows simultaneous evaluation of the heart structure and function and of the aortic valve. Given improved options for intervention, the study of postoperative aortic remodeling to evaluate the efficacy of surgery has attracted extensive attention. However, few studies utilize color Doppler ultrasound in the evaluation of post-operative AD. Recently, the preoperative and post-operative ventral segment and its far true and false lumen hemodynamics were observed quantitatively by color Doppler ultrasound. The direction, velocity and spectrum of the lesional blood flow were analyzed, which provided improved assessment of true and false lumen pressures. The morphological and hemodynamic status of main branches of AD before and after surgery including carotid, subclavian artery, celiac axis, superior mesenteric artery, and iliac artery were analyzed by color doppler ultrasound, which could provide more valuable information for the diagnosis, treatment and prognosis evaluation of AD.

## 9. Conclusion

Aortic CTA and MRI are superior to ultrasound for the imaging of AD's location and morphological structure because of a greater field of view. But ultrasound is useful complementary to Aortic CTA and MRI for the dynamic observation of morphological structure and hemodynamic changes. Ultrasound is portable, rapid, accurate, and cost-effective in the diagnosis and follow-up of AD.

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## Conflict of interest

The authors declare that there is no conflict of interest.

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