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Echocardiography in aortic diseases: EAE recommendations for clinical practice

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Echocardiography plays an important role in the diagnosis and follow-up of aortic diseases. Evaluation of the aorta is a routine part of the standard echocardiographic examination. Transthoracic echocardiography (TTE) permits adequate assessment of several aortic segments, particularly the aortic root and proximal ascending aorta. Transoesophageal echocardiography (TOE) overcomes the limitations of TTE in thoracic aorta assessment. TTE and TOE should be used in a complementary manner. Echocardiography is useful for assessing aortic size, biophysical properties, and atherosclerotic involvement of the thoracic aorta. Although TOE is the technique of choice in the diagnosis of aortic dissection, TTE may be used as the initial modality in the emergency setting. Intimal flap in proximal ascending aorta, pericardial effusion/tamponade, and left ventricular function can be easily visualized by TTE. However, a negative TTE does not rule out aortic dissection and other imaging techniques must be considered. TOE should define entry tear location, mechanisms and severity of aortic regurgitation, and true lumen compression. In addition, echocardiography is essential in selecting and monitoring surgical and endovascular treatment and in detecting possible complications. Although other imaging techniques such as computed tomography and magnetic resonance have a greater field of view and may yield complementary information, echocardiography is portable, rapid, accurate, and cost-effective in the diagnosis and follow-up of most aortic diseases.

Keywords Aortic diseases • Transoesophageal echocardiography • Transthoracic echocardiography • Contrast echocardiography

Introduction

Aortic diseases are an important cause of cardiovascular morbidity and mortality. Except when complications are life-threatening, such as acute aortic syndrome or aortic rupture, aortic diseases are asymptomatic and without abnormalities on physical examination; thus, diagnosis and follow-up depend exclusively on imaging techniques. Echocardiography has become the most used imaging test in the evaluation of cardiovascular disease and plays an important role in the diagnosis and follow-up of aortic diseases. The aorta is divided into segments: the aortic root, ascending aorta, aortic arch, descending aorta, and abdominal aorta. Ultrasound techniques for imaging of the aorta include transthoracic echocardiography (TTE), transoesophageal echocardiography (TOE), abdominal ultrasound, and intravascular ultrasound (IVUS). In the present article, we will focus on TTE and TOE methodologies in the assessment of aortic diseases, their strengths and limitations for its use in various clinical situations and recommendations for appropriate applications of

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echocardiography based on available evidence. It is not the main objective of this manuscript to compare the usefulness of echocardiography with other imaging techniques or to describe the standard diagnostic management of different aortic diseases.

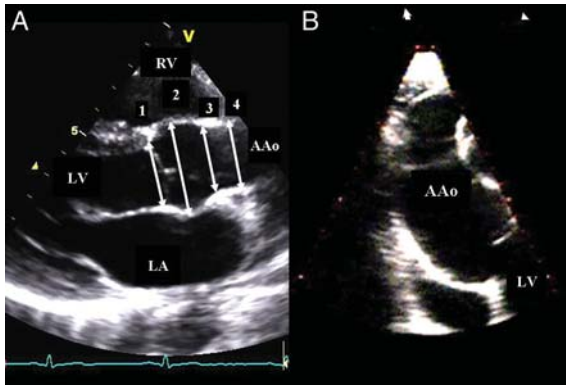

Figure 1 Transthoracic echocardiography. (*A*) Parasternal long-axis view (transthoracic echocardiography). The following diameters are shown: outflow tract diameter (1), sinuses of Valsalva (2), sinotubular junction (3), and tubular ascending aorta (4). (*B*) Right parasternal long-axis view, mid and distal parts of ascending aorta may be visualized. AAo, ascending aorta; LA, left atrium; LV, left ventricle; RV, right ventricle.

Transthoracic echocardiography

Echocardiographic evaluation of the aorta is a routine part of the standard echocardiographic examination.[1] Although TTE is not the technique of choice for overall assessment of the aorta, it is useful for the diagnosis and follow-up of some segments of the aorta. TTE is one of the techniques most used to measure proximal aortic segments in clinical practice. Using different windows, the proximal ascending aorta is visualized in the left and right parasternal long-axis views (*Figure 1*) and, to a lesser extent, in basal short-axis views. The long-axis view affords the best opportunity for measuring aortic root diameters by taking advantage of the superior axial image resolution. In all patients with suspected aortic disease, the right parasternal view is recommended for estimating the true size of the ascending aorta. The ascending aorta is also visualized in the apical long-axis and modified apical five-chamber views; however, in these views, the aortic walls are seen with suboptimal lateral resolution. Modified subcostal views may in some cases (more frequently in children) be helpful, but here the ascending aorta is far from the transducer. All these views also permit assessment of the aortic valve, which is often involved in diseases of the ascending aorta (e.g. bicuspid valve, aortic regurgitation due to dilatation of the ascending aorta or aortic dissection, and other diseases).

Of paramount importance for evaluation of the thoracic aorta is the suprasternal view (*Figure 2A*). This view primarily depicts the aortic arch and the three major supra-aortic vessels (innominate, left carotid, and left subclavian arteries), with variable lengths of the descending and, to a lesser degree, ascending aorta. Although

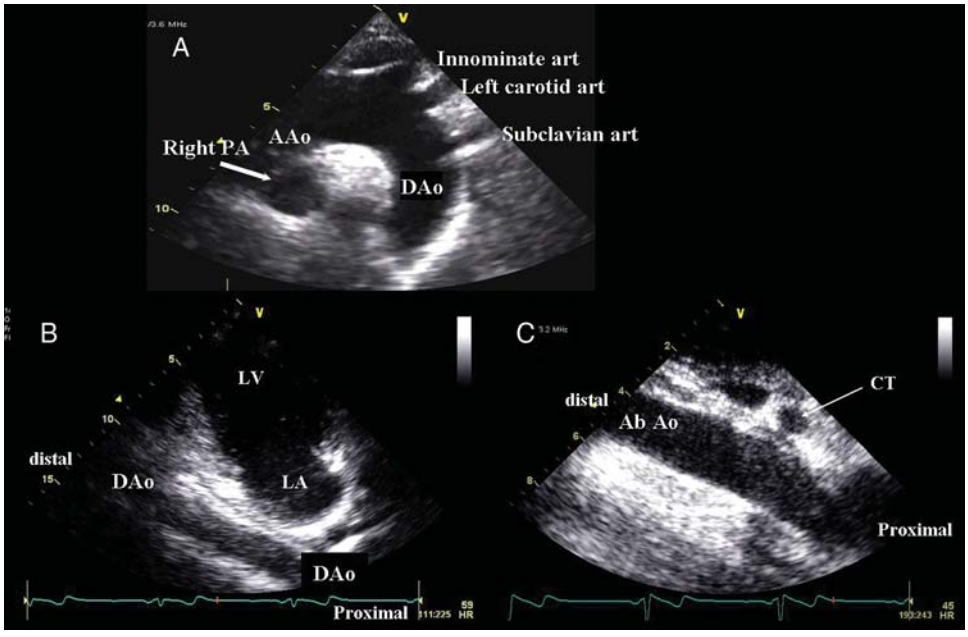

Figure 2 (*A*) Suprasternal view of aortic arch and supra-aortic great arteries. (*B*) Mid part of the descending thoracic aorta visualized by long-axis view from apical window. (*C*) Abdominal aorta visualized by subcostal view. In non-obese patients, it is not difficult to visualize distal abdominal aorta. art, artery; PA, pulmonary artery; AAo, ascending aorta; DAo, descending aorta; CT, coeliac trunk.

this view may be obstructed, particularly in patients with emphysema or short, wide necks, it should be systematically sought if aortic disease is evaluated. From this window, aortic coarctation can be visualized and functionally evaluated by continuous-wave Doppler; a persistent ductus arteriosus may also be identifiable by colour Doppler. Dilatation and aneurysm, plaque, calcification, thrombus, or a dissection membrane are detectable if image quality is sufficient. A systematic comparison of harmonic TTE and TOE made to detect aortic plaques and thrombi revealed high sensitivity for the detection of aortic arch atheromas protruding ≥4 mm into the lumen.[2]

Table 1 Echocardiographic views of the aorta

View	Part of aorta
Transthoracic echo	
Parasternal long + short axis	Ascending + descending thoracic
Apical four-chamber	Descending thoracic
Apical two-chamber and/or long axis	Descending thoracic
Suprasternal	Arch, descending + ascending thoracic
Subcostal	Abdominal (+ascending thoracic)
Transoesophageal echo	
Upper oesophageal long + short axis	Ascending thoracic
Aortic (long + short axis)	Descending thoracic + arch

The entire thoracic descending aorta is not well visualized by TTE. A short-axis view of the descending aorta can be imaged posteriorly to the left atrium in the parasternal long-axis view. From the apical window, a short-axis cross-section of the descending aorta is seen lateral to the left atrium in the four-chamber view and a long-axis stretch in the two-chamber view. By 90° transducer, a rotation long-axis view is obtained and a mid part of the descending thoracic aorta may be visualized (*Figure 2B*). Although a partial assessment of the size of the descending aorta and detection of large abnormal structures such as dissection membranes are possible in these views, the descending aorta lies far from the transducer and the assessment is incomplete, suboptimal and not accurate. However, in acute aortic syndrome with left pleural effusion, scanning from the back may provide good or optimal views of the descending aorta.

In contrast, since the abdominal descending aorta is relatively easily visualized to the left of the inferior vena cava in sagittal (superior–inferior) subcostal views, the systematic search for abdominal aortic aneurysms has been advocated as part of the routine echocardiographic exam[3,4] (*Figure 2C*), although transthoracic echo transducers are not optimal for abdominal sonography.

In summary, although TTE is not the ideal tool for visualizing all aortic segments, important information can always be gained by careful use of all echo windows (*Table 1*).

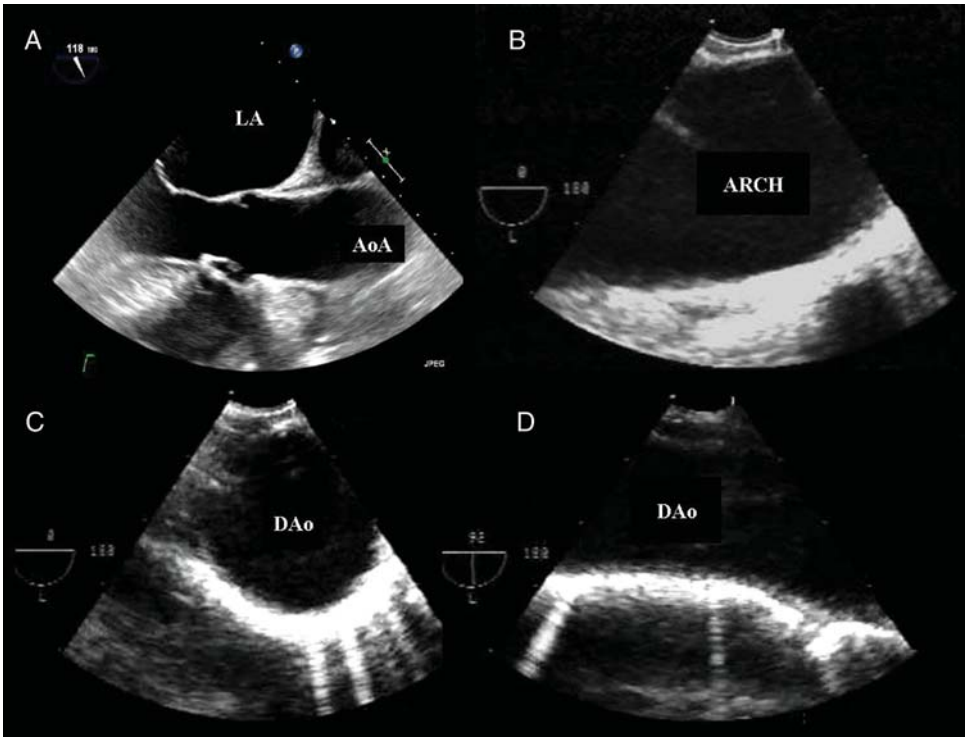

Figure 3 Transoesophageal echocardiography. (*A*) Ascending aorta in long-axis view at 120°. (*B*) Aortic arch in transverse view. (*C*) Descending aorta visualized by transverse view. (*D*) Descending aorta visualized by longitudinal view.

Recommendation

TTE permits adequate assessment of several aortic segments, particularly the aortic root and proximal ascending aorta. All scanning planes should be used to obtain information on most aortic segments. However, if inconclusive information or abnormalities are present, another imaging modality is required to either complete or add diagnostic information.

Transoesophageal echocardiography

Proximity of the oesophagus and the thoracic aorta permits high-resolution images from higher-frequency TOE. Furthermore, the availability of multiplane imaging permits improved incremental assessment of the aorta from its root to the descending aorta.[5] The most important transoesophageal views of the ascending aorta, aortic root and aortic valve are the high transoesophageal long-axis (at 120°–150°) (*Figure 3A*) and short-axis (at 30°–60°) views. A short segment of the distal ascending aorta, just before the innominate artery, remains unvisualized owing to interposition of the right bronchus and trachea (blind spot). Images of the ascending aorta often contain artefacts due to reverberations from the posterior wall of the ascending aorta or the posterior wall of the right pulmonary artery, presenting as aortic intraluminal linear horizontal lines moving in parallel with the reverberating structures, as can be ascertained on M-mode tracings.[6] The descending aorta is easily visualized in short-axis (0°) and long-axis (90°) views from the coeliac trunk to the left subclavian artery (*Figure 3C* and *D*). Further withdrawal of the probe shows the aortic arch, where the inner curvature and anterior arch wall are usually well seen all the way to the ascending aorta. In the distal part of the arch (*Figure 3B*), the origin of the subclavian artery is easily visualized. However, in awake patients, the origin of innominate and left carotid arteries is not clearly visualized, although in anaesthetized patients, it is possible to identify the origin of these supra-aortic arteries.[7] The proximal part of the coeliac trunk is visualized in most cases and the superior mesenteric artery in 50% of cases.[8] One of the limitations of TOE is to locate the exact level of a given abnormality in the descending aorta. When no reference vessels, such as subclavian artery or coeliac trunk, are visualized, this limitation can be overcome by rotating the transducer and identifying the level of the descending aorta in comparison with the structures of the heart or great vessels (anterior structures). Like the ascending aorta, the descending aorta often produces an artefactual pseudo-aorta located posteriorly to the true aorta ('double-barrel aorta').

Recommendation

TOE is the ultrasound technique of choice in thoracic aorta assessment and provides high-resolution images of the entire thoracic aorta except for a small portion of the distal ascending aorta near the innominate artery. TOE overcomes limitations encountered by TTE. TTE and TOE should be used in a complementary manner.

Aorta size

Measurements of aortic diameter by echocardiography are accurate and reproducible when care is taken to obtain a true perpendicular dimension and gain settings are appropriate. Standard measurement conventions established the leading edge-to-leading edge diameter in end-diastole,[9] and the normative data published in the literature were obtained using the leading edge technique.[10–12] Some experts[13,14] favour inner edge-to-inner edge diameter measurements to increase reproducibility and match those obtained by other methods of imaging the aorta. However, recent improvements in echocardiographic image quality and resolution minimize the differences between these measurement methods. Two-dimensional (2D) aortic measurements are preferable to M-mode, as cyclic motion of the heart and resultant changes in M-mode cursor location result in systematic underestimation by 1–2 mm of aortic diameter by M-mode in comparison with the 2D aortic diameter. Standard diameter measurements are at the aortic annulus, at the level of the sinuses of Valsalva and at the sinotubular junction (*Figure 1*). Aortic annular diameter is measured between the hinge points of the aortic valve leaflets (inner edge–inner edge) in the left parasternal long-axis view, during systole, which reveal the largest aortic annular diameter. In a normal ascending aorta, the diameter at sinus level is the largest, followed by the sinotubular junction and the aortic annulus. If aortic dilatation is detected at any level, its maximum diameter should be measured and reported.

Normal values

Aorta size is related most strongly to body surface area (BSA) and age.[10,11] Therefore, BSA may be used to predict aortic root diameter in several age intervals. Roman *et al.*[10] considered three age strata: younger than 20 years, 20–40 years, and older than 40 years by published equations. These normal values have been accepted to date as the reference values. Some groups have suggested indexing by height to avoid the influence of overweight on BSA. Nevertheless, large series defining normal ranges of this index are lacking. Aortic root dilatation at the sinuses of Valsalva is defined as an aortic root diameter above the upper limit of the 95% confidence interval of the distribution in a large reference population. In adults, a diameter of 2.1 cm/m^2 has been considered the upper normal range in ascending aorta.[15] TTE suffices to quantify maximum aortic root and proximal ascending aorta diameters when the acoustic window is adequate. Nevertheless, the technique is more limited for measuring the remaining aortic segments. TOE overcomes part of these TTE limitations by affording better measurement of aortic arch and descending thoracic aorta size. TOE may make oblique measurements when the descending aorta is elongated or tortuous. To avoid this overestimation, aortic diameter measurement by TOE should be attempted only when circular sections are obtained. Measurements of descending thoracic aorta in short axis and of the aortic arch in long axis are recommended. The absolute and indexed normal values of the various aortic segments are shown in *Figure 4*.

Recommendation

TTE permits precise and reproducible measurements of the diameters of the aortic root and proximal part of the ascending aorta. The relationship between aorta size and age and body surface should be considered when defining normal ranges. Given its

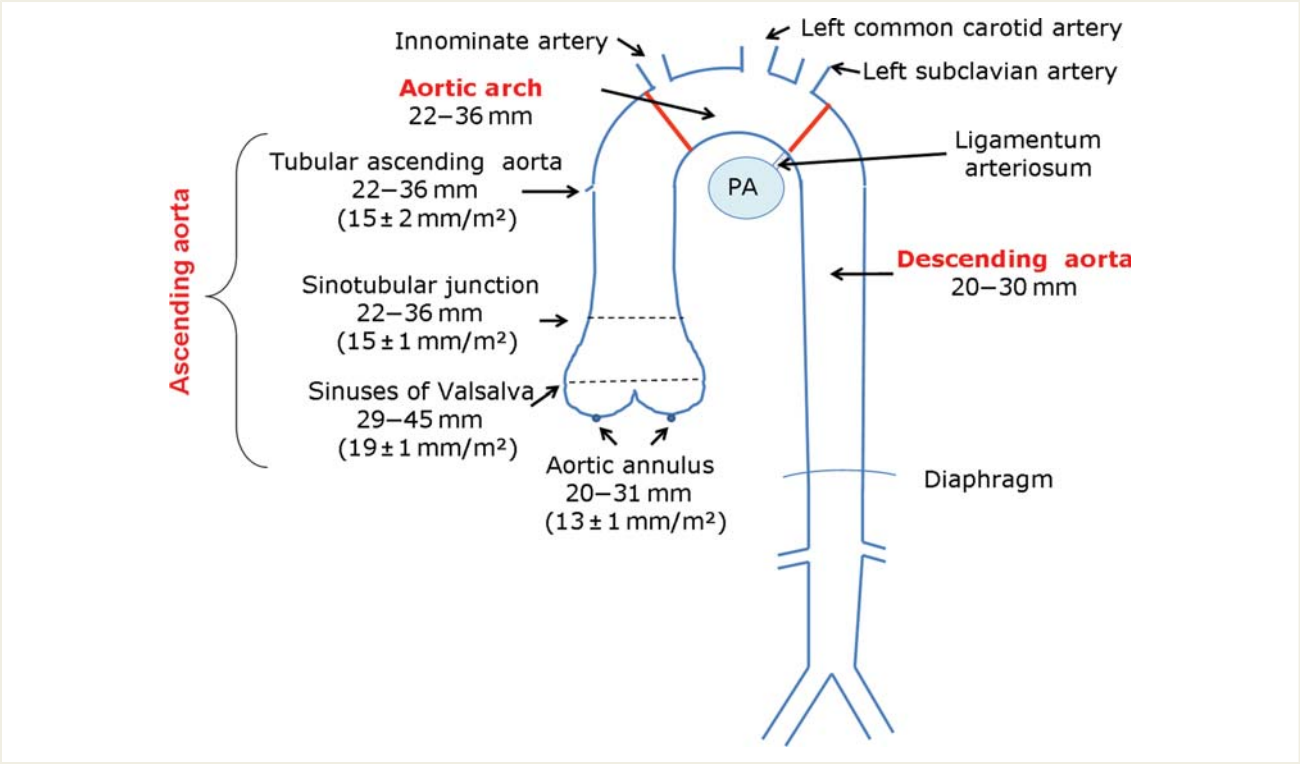

Figure 4 Normal size of thoracic aortic segments. The thoracic aorta can be divided into three segments: the ascending aorta that extends from the aortic annulus to the innominate artery and is typically measured at the level of the aortic annulus, the sinuses of Valsalva, the sinotubular junction, and the proximal (tubular) ascending aorta; the aortic arch that extends from the innominate artery to the ligamentum arteriosum; and the descending aorta that extends from the ligamentum arteriosum to the level of the diaphragm. PA, right pulmonary artery. Modified from Diseases of the aorta. In: Feigenbaum H, Armstrong WF, Ryan T, eds. *Feigenbaum's Echocardiography*. 6th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2005. p673; Ascending aorta values from Erbel *et al.*[46]

better visualization, TOE is the ultrasound modality of choice for measuring the size of the aortic arch and descending aorta.

Aortic and arterial biophysical properties

The aorta plays an important role in modulating left ventricular performance and arterial function throughout the entire cardiovascular system.[16] Arterial function is modified by several factors that affect the arterial wall and is reliably assessed by non-invasive methods.[17] The velocity of the pulse wave is fast enough for it to be able to travel to the periphery and then return within a single cardiac cycle. The elastic properties of arteries vary along the arterial tree, with more elastic proximal arteries and stiffer distal arteries. A comprehensive assessment of aortic and arterial biophysical properties includes: (i) evaluation of the aortic pressure–dimension relationship; (ii) arterial stiffness (measured by wave velocities); and (iii) the reflected waves.[16,17]

Aortic pressure–dimension relationship

An increase in distending pressure during systole induces an increase in aortic dimension, which is directly related to the elastic properties of the aorta. Diameter or area changes can be determined using TTE or TOE, but estimation of the pressure changes at the same site may be unreliable because of the amplification of the pulse pressure (i.e. systolic pressure increases progressively towards the periphery) and inaccuracy of all cuff sphygmomanometer systems, particularly in young subjects. However, studies have shown a good correlation between aortic distensibility calculated using echocardiography and non-invasive brachial artery pressure measurements and aortic distensibility calculated invasively, using contrast aortography and direct aortic pressure recordings. Changes in arterial diameter can be measured at the level of the ascending aorta, ~3 cm above the aortic valve in 2D-guided M-mode of parasternal long-axis view, with the diastolic aortic diameter measured at the peak of the QRS complex and systolic aortic diameter measured at the maximal anterior motion of the aorta. Other levels for measuring the arterial diameters are limited to the mid-portion of the abdominal aorta.

There are several indices derived from aortic or arterial dimensions and pressures and used for the estimation of the elastic properties of the aorta. The indices most frequently used are aortic/arterial distensibility (the relative change in diameter or area for a pressure change), compliance (the absolute change in diameter or area for pressure), and a non-dimensional index of local arterial stiffness named the β-index [defined as the ratio of logarithm

(systolic/diastolic pressures) to relative change in diameter][17–19] which is less affected by arterial pressure changes and is easily measured using echo-tracking devices.[17] In Marfan patients, aortic stiffness proved to have an important value in predicting progressive aortic dilatation.[20,21] Also, indices of aortic stiffness are used in clinical studies for the assessment of the efficacy of different therapeutic regimens in these patients.[22] Abnormal aortic elastic properties were demonstrated also in patients with bicuspid aortic valve with no or mild aortic valve impairment.[23]

Pulsed-wave velocity

Pulsed-wave velocity (PWV) is defined as the travel speed throughout the aorta of the pulse wave. With increased aortic stiffness, PWV increases. PWV is expressed as the ratio of the distance between the two sites at which the onset of the wave is being recorded to the time of travel of the wave from the proximal to the distal sites. Accordingly, carotid–femoral PWV is considered the gold standard measurement of arterial stiffness and is the most widely used index.[16] PWV can be assessed by echocardiography, measuring the time from the QRS to the onset of the pulsed-wave Doppler envelope in proximal (carotid artery, ascending aorta) and distal (femoral artery, descending aorta) sites (the difference between them is the transit time), and the pulsed wavelength between the two points where the Doppler tracings were recorded.[17,19] Normal PWV values increase from 4–5 m/s in the ascending aorta to 5–6 m/s in the abdominal aorta.[24] The independent prognostic value of PWV, as an index of aortic stiffness, for all-cause and cardiovascular mortality has been demonstrated in different populations including hypertensive, diabetic, or renal patients, the elderly, and the general population.[16,25–27]

Reflected waves

When the stiffness of the aorta and the large arteries is increased, PWV is increased and the backward waves from the periphery return early to the ascending aorta, thereby increasing central systolic and decreasing central diastolic blood pressure.[17] The point where the incident wave merges with the reflected one can be identified in the central waveform and thus the augmented pressure, the difference between the merging point (shoulder of the waveform) and the peak systolic pressure, is computed.[17] Augmentation index, calculated as the ratio between the augmentation pressure and the pulse pressure and expressed as a percentage, is an index used for the evaluation of the reflected wave function. Echo-tracking systems implemented in echocardiographic machines are able to measure this index at carotid level.[17] As with PWV, wave reflection indices have been demonstrated to be independent predictors of cardiovascular events in several diseases.

Recommendation

Aortic and arterial biophysical properties can be easily and reliably assessed by echocardiography and provide important pathophysiological and prognostic information that may have clinical implications both in disease states and in the general population.

Aortic atherosclerosis

The presence of detectable atherosclerotic plaques in the aorta indicates the presence of atherosclerotic disease and is a possible source of embolism.[28] Aortic atheromas are characterized by irregular intimal thickening of at least 2 mm, with increased echogenicity. They often have superimposed mobile components, mainly thrombi. The morphology of atheromatous plaques is dynamic, with frequent formation and resolution of mobile components.[29] TOE is the imaging modality of choice for diagnosing aortic atheromas. It provides higher-resolution images than TTE and has good interobserver reproducibility.[30] However, suprasternal harmonic imaging by TTE also permits the visualization of protruding arch atheromas in many cases[2] and may be helpful in the routine assessment of the source of embolism. The prevalence of aortic atheromas on TOE varies depending on the population studied. In a community-based TOE study, aortic atheromas were present in 51% of the population over 45 years, being complex in 7.6%.[31] Atheroma prevalence increased with age, smoking, and pulse pressure. TOE characterizes the plaque by assessing plaque thickness, ulceration, calcification and superimposed mobile thrombi, thereby determining the embolic potential of each plaque. The advantages of TOE over other non-invasive modalities include its ability to assess the mobility of plaque in real time. Another echocardiographic modality is intraoperative epiaortic ultrasound which facilitates the selection of a suitable aortic clamping site by avoiding calcifications with an increased risk of embolization.

The French Aortic Plaque in Stroke group showed that increasing plaque thickness of $\geq$4 mm is associated with a significantly increased embolic risk.[32] The presence of mobile lesions (thrombi) superimposed on aortic atheromas has been recognized to imply a high embolic risk. Other characteristics of the lesions seen on TOE, such as ulceration $\geq$2 mm in aortic plaques and non-calcified plaques, were also associated with a higher risk of stroke.[33] Thus, atherosclerotic plaques are defined as complex in the presence of protruding atheromas of $>$4 mm in thickness, mobile debris, or the presence of plaque ulceration, and defined as simple if the plaques lack these morphological features. Two recent community-based studies found no association between aortic atheromas and future stroke.[31,34] An alternative explanation is that atheromatous plaque is merely a marker for diffuse atherosclerosis that predisposes patients to systemic embolism by other cardiovascular mechanisms.

The embolic potential of atherosclerotic aortic lesions during invasive procedures or during open-heart surgery is well established.[35,36] Some studies have shown the risk of stroke or peripheral embolism after cardiac catheterization or intra-aortic balloon pump placement in patients with severe aortic atherosclerosis diagnosed by TOE.[35] A strong association between aortic stenosis and aortic atherosclerosis has recently been established.[37] The presence of plaques in the aorta of patients with aortic stenosis has important implications since these patients often undergo invasive diagnostic and therapeutic procedures that can dislodge particularly thick plaques and the attached thrombotic material.

Large mobile aortic thrombi are possible causes of systemic emboli and appear to be a complication of atherosclerosis. TOE is the best technique for diagnosing and monitoring the evolution of these large thrombi.[38] The optimal management of these complications remains to be defined. Anticoagulation therapy appears to be a logical approach, although surgical removal has been indicated in cases with recurrent embolic events.[39]

Recommendation

TOE is the imaging modality of choice for diagnosing aortic atheromas. Advantages of TOE over other non-invasive modalities [computed tomography (CT) and magnetic resonance imaging (MRI)] include the accurate measurement of size and mobility of the plaque in real time. When atherosclerosis is present, the severity and location of the most severe atheromas should be reported. The suprasternal window may be useful for the diagnosis of plaques in the aortic arch by TTE when the acoustic window is optimal.

Aortic aneurysm

TTE is an excellent modality for imaging aortic root dilatation,[10,13,14] which is important for patients with annuloaortic ectasia, Marfan syndrome, or bicuspid aortic valve. Since the predominant sites of dilatation are in the proximal aorta, TTE often suffices for screening (*Figure 5*). In ascending aorta dilatation, some echocardiographic features play an important role in the assessment of the mechanisms of functional aortic regurgitation. Functional classification of aortic root abnormalities responsible for aortic insufficiency has been suggested.[40–42] This classification is based on assessment of leaflet function and aortic root size and provides important information for surgical management strategies. Tethering of the leaflets is the feature most closely associated with functional aortic regurgitation. This tethering depends on the sinotubular junction/annulus mismatch. This information is useful for targeting the optimal time and strategy for aortic valve-sparing surgery in the setting of ascending aorta aneurysms (*Table 2*). Thus, tethering of aortic leaflets might be useful to monitor the progressive impact of sinotubular junction dilatation on valve function in patients with ascending thoracic aorta aneurysm for valve-sparing surgery to be indicated before leaflet damage occurs.

TTE suffices in the assessment of proximal ascending aorta when the acoustic window is adequate. However, TOE is clearly superior to TTE for assessing aneurysms located in the aortic arch and descending thoracic aorta. However, TOE is limited in tortuous aortas, since in these cases, the aorta may be separated from the oesophagus, resulting in inability to image these aorta segments. Thus, the modalities of choice are MRI and CT. Although TTE transducers are not optimal for assessing the abdominal aorta, the segment of the aorta between the coeliac trunk and renal arteries is frequently well visualized. The presence of abdominal aorta aneurysms in patients with atherosclerosis or aortic diseases is not uncommon and assessment of the abdominal aorta may be useful.

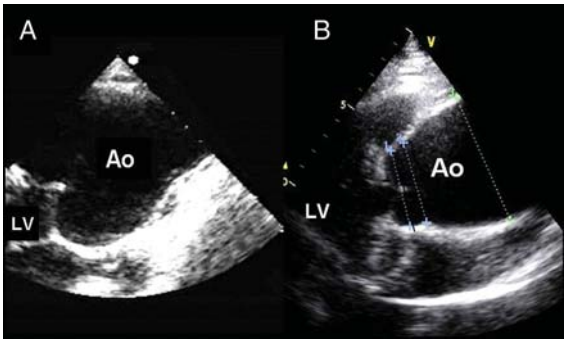

Figure 5 Parasternal long-axis view by transthoracic echocardiography. (*A*) Annuloaortic ectasia with pyriform morphology. (*B*) Ascending aorta aneurysm located in the upper part of the sinotubular junction.

Table 2 Determinants of functional aortic regurgitation with anatomically normal aortic valve and ascending aorta aneurysm by transoesophageal echocardiography

Annulus, Valsalva sinuses, sinotubular junction, and tubular tract dimensions
Coaptation leaflet height: maximum distance between protodiastolic coaptation of the leaflet tips and the annulus plane. Diastolic tenting of the leaflets >8–10 mm
Sinotubular junction/annulus ratio >1.6

Recommendation

In aortic root aneurysms, the accurate measurement of diameters by TTE or TOE is crucial for surgical indication and surgical management strategies. In the arch and descending aorta, other imaging modalities with better reproducibility and larger field of view, such as CT or MRI, may be more suitable.

Acute aortic syndrome diagnosis

Acute aortic syndrome has a high mortality rate and early medical and surgical treatment is crucial. Therefore, rapid and accurate diagnostic techniques, which can be applied in critically ill patients, are essential. The diagnosis of acute aortic syndrome can be made with similar accuracy using different imaging techniques such as TOE, CT, or MRI;[43] however, the decision to use a specific technique depends on two major factors: availability of the techniques and experience of the imaging staff. Compared with other highly accurate diagnostic techniques (CT and MR), echocardiography has the advantage of being applicable in any hospital setting (emergency, intensive care, and operating theatre), without the need to transfer the patient who is often in an unstable haemodynamic situation, monitored, and with intravenous drugs. However, in two large registries, the international registry of acute aortic dissection[44] and the Spanish registry of acute aortic syndrome,[45] CT was the first most used imaging technique in the diagnosis of dissection, (61 and 77%, respectively). A possible explanation for this fact is that patients with acute aortic syndrome are usually admitted to the emergency departments of community hospitals where TOE may not be available. Nevertheless, it should be emphasized that even in experienced centres, most patients with acute aortic syndrome undergo more than one imaging modality; this syndrome is much too critical to leave room for diagnostic doubts.

Echocardiographic diagnosis

Aortic dissection and its variants, included in the ESC classification of aortic dissection,[46] can be correctly diagnosed by

echocardiography. The diagnosis of classical aortic dissection is based on the demonstration of the presence of an intimal flap that divides the aorta into two, true and false, lumina. In most cases, false lumen flow is detectable by colour Doppler but may be absent in totally thrombosed and retrograde dissections. Intramural haematoma is characterized by circular or crescentic thickening of the aortic wall >5 mm and penetrating aortic ulcer (PAU) presents as an image of crater-like outpouching with jagged edges in the aortic wall, generally associated with extensive aortic atheromas.

Transthoracic echocardiography

Classically, TTE has been considered limited in the diagnosis of aortic dissection. In older series, sensitivity in the diagnosis of ascending aorta dissection was 78–90% but only 31–55% in descending aortic dissection. Specificity for type A aortic dissection was reported to range from 87 to 96% and for type B dissection 60–83%.[47] However, these data are derived from old studies when the current imaging technology, such as harmonic imaging, was not available. Recently, harmonic imaging (*Figure 6*) and the use of contrast enhancement have been shown to improve the sensitivity and specificity of TTE in the diagnosis of aortic dissection.[48] Contrast-TTE has similar accuracy to TOE in the diagnosis of type A aortic dissection (sensitivity 93% and specificity 97%), although it is more limited in type B involvement (sensitivity 84% and specificity 94%), mainly in the presence of non-extended dissection, intramural haematoma, and aortic ulcers.[48] However, given its availability, rapidity, and additional information on cardiac status, TTE may be used as the initial imaging modality when aortic dissection is clinically suspected in the emergency room.[49] The low negative predictive value of TTE does not permit dissection to be ruled out, and further tests will be required if the TTE exam is negative. The value of TTE is also limited in patients with abnormal chest wall configuration, obesity, pulmonary emphysema, and in those on mechanical ventilation. These limitations may prevent adequate decision-making in some cases, but have been overcome by TOE. In patients with acute chest pain, special attention should be paid during the TTE exam to aortic root dilatation, aortic regurgitation, and/or pericardial effusion, since these findings should raise the suspicion of acute aortic syndrome. If a dissection cannot be directly visualized, other imaging techniques are mandatory (*Figure 7*).

Transoesophageal echocardiography

TOE has constituted a decisive advance in the diagnosis of aortic dissection. It can image the entire thoracic aorta except for a small portion of the distal ascending aorta near the proximal arch. The proximity of the oesophagus to the aorta, without interference from the chest wall or lung, permits high-quality images to be obtained (*Figure 8*).

Since the first multicentre European Cooperation study by Erbel *et al.*,[47] several studies have demonstrated the accuracy of TOE in the diagnosis of aortic dissection with sensitivity of 86–100%, specificity 90–100%, and a negative predictive value of 86–100%.[47–50] The low specificity of the technique described in some series[51] is explained by the fact that the majority of

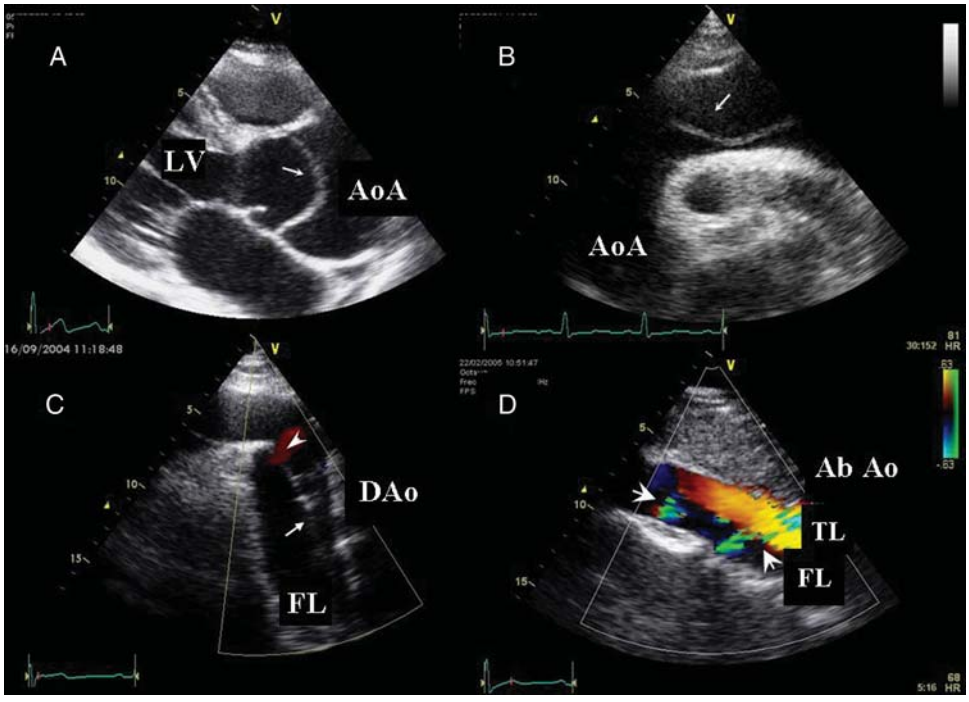

Figure 6 Aortic dissection diagnosis by transthoracic echocardiography. Intimal flap (arrows) and two lumina are visualized in: (*A*) aortic root, (*B*) aortic arch and distal ascending aorta, (*C*) proximal descending aorta (arrowhead shows the entry tear), and (*D*) dissection of abdominal aorta. Colour Doppler helps to identify the true lumen (TL). Arrowheads signal secondary communications.

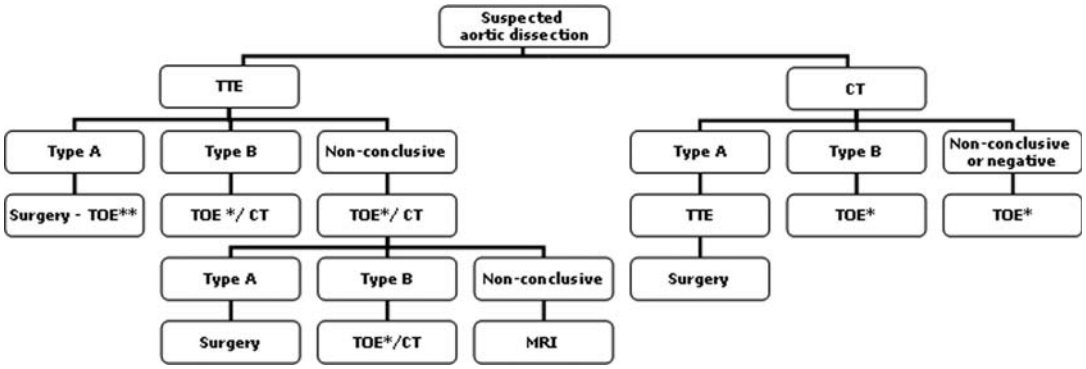

Figure 7 Algorithm of diagnostic strategy of acute aortic dissection depending on whether the first test was transthoracic echocardiography or computed tomography. *Depending on availability, complications, and examiner experience. **Definitive diagnosis of type A dissection by transthoracic echocardiography permits the patient to be sent directly to surgery provided intraoperative transoesophageal echocardiography is performed before surgery.

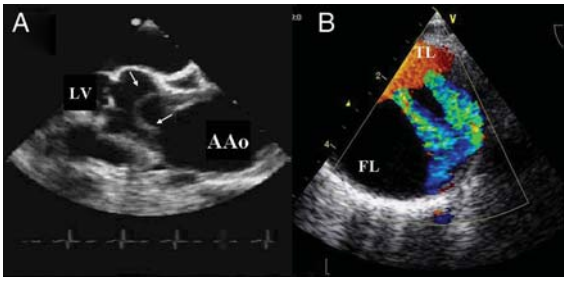

Figure 8 Transoesophageal echocardiography. (*A*) ascending aorta dissection by long-axis view. Arrows show the intimal flap. (*B*) descending thoracic aorta dissection by transverse view. Two jets from true lumen to false lumen identified the presence at secondary communications.

intraluminal images in the ascending aorta were considered diagnostic of dissected intima. The analysis of larger studies[6,47,50,51] showed that 3.5% of cases with clinically suspected dissection were erroneously diagnosed as having ascending aorta dissection. Altogether, the experience accumulated in recent years demonstrates that the presence of an intraluminal linear image in the ascending aorta alone should not be accepted as a dissection criterion. In the ascending aorta, particularly when dilated, linear reverberation images are very common, being observed in 44–55% of studies.[6] Artefacts in the aortic root are a reverberation from the anterior wall of the left atrium. In the middle third of the ascending aorta, they are due to reverberations from the posterior wall of the right pulmonary artery. The assessment of location and movement of these intraluminal images by M-mode echocardiography is the best way to differentiate between intimal flap and imaging reverberations. Typically, intraluminal reverberations in the aortic root are located twice as far from the transducer as the posterior aortic wall, and their movement is parallel to the posterior aortic wall but with double displacement amplitude. Intraluminal reverberations in ascending aorta are located at twice the distance from the right pulmonary artery posterior wall as from the posterior aortic wall.[6]

TOE is clearly superior to TTE in the diagnosis of intramural haematoma and aortic ulcers. Echocardiographic findings of intramural haematoma are circular or crescentic thickening (>5 mm) of the aortic wall (*Figure 9A* and *B*) and there should be no flow within.[52–54] Diagnosis is straightforward in typical cases, but the haematoma may sometimes be mistaken for an intraluminal thrombus or a dissection with thrombosed false lumen. Displacement of intimal calcification caused by accumulation of blood within the aortic media is useful for the differential diagnosis. Usually, the inner margin of intramural haematoma is smooth, and aortic thickening occurs beneath the bright echo-dense intima, whereas an irregular margin with dilated aorta is commonly observed in patients with aneurysmal dilatation and mural thrombi. In some cases, echolucent areas are present but no flow into these areas is detected. Intramural haematoma is quite easily differentiated from classical aortic dissection with flow in two lumina. However, the diagnosis can be difficult when the false lumen of dissection is totally thrombosed.[55,56]

Diagnosis of penetrating ulcers by echocardiography is based on the image of crater-like outpouching of the aortic wall, generally associated with extensive aortic atheroma[57] (*Figure 9C*). Although both CT and MRI permit an easy diagnosis of these images because of their larger field of view, TOE may provide better information on the differential diagnosis of ulcerated plaques, penetrating atherosclerotic ulcers or ulcer-like images secondary to focal intimal rupture in the evolution of intramural haematomas. Aortic wall thickening with inward displacement of intimal calcification was an indication of associated intramural haematoma.

TOE is semi-invasive and requires sedation and may cause a rise in systemic pressure from retching and gagging. Although isolated cases of aortic rupture during the procedure have been reported, the incidence in prospective series is very low, being more related to the intrinsic risk of the disease than the procedure itself, as these events also occur during CT or MRI. However, adequate sedation with strict blood pressure control is mandatory. When

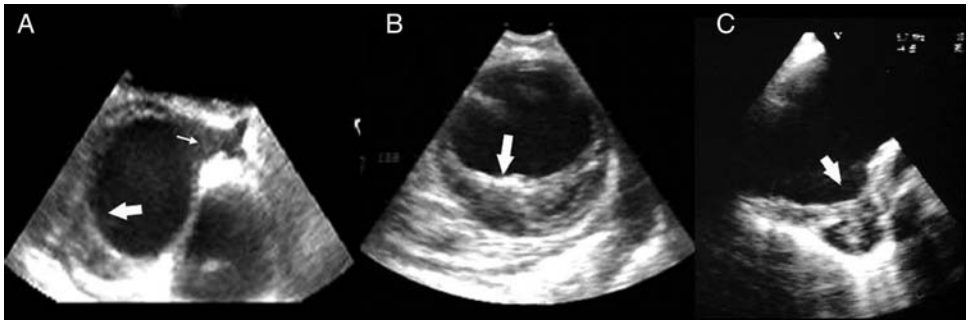

Figure 9 Transoesophageal echocardiography. (*A*) Crescentic intramural haematoma in ascending aorta (large arrow) adjacent to the left main coronary ostium (small arrow). (*B*) Intramural haematoma in descending aorta. Arrow shows intima calcification. (*C*) Penetrating aortic ulcer deforming the adventitia (arrow).

therapeutic decision-making is definitive by other techniques, TOE should be performed in the operating theatre before surgery or when the patient is haemodynamically stable with no chest pain. Given its accuracy in the diagnosis of aortic dissection, intramural haematoma and aortic ulcers, TOE is a technique of choice in acute aortic syndrome diagnosis when an expert echocardiographer is available.

Recommendation

Although TOE is the technique of choice in aortic dissection diagnosis, TTE may be used as the initial imaging modality in the emergency setting. Contrast may improve its accuracy. If the diagnosis of type A dissection by TTE or contrast-TTE is definitive, surgical treatment could be directly indicated, provided intraoperative TOE is performed just prior to surgery to confirm the diagnosis. In suspected type B dissections, TOE or CT should be performed according to clinical presentation, complications, and examiner experience. When contrast-TTE fails to show abnormalities, another imaging technique must be applied for acute aortic syndrome to be definitively ruled out.

Diagnosis of morphological and haemodynamic findings in aortic dissection

TOE permits assessment of the main anatomical and functional aspects of interest for the management of aortic dissection.

Intimal tear location

The intimal tear appears as a discontinuity of the intimal flap. TOE provides a direct image of the tear and permits its measurement. Erbel *et al.*[55] demonstrated a different evolutive pattern according to the presence and location of the tear. TOE permits identification of the tear in 78–100% of cases.[55] Colour Doppler can reveal the presence of multiple small communications between the two lumina, especially in descending aorta. Anatomical controls showed that most of these communications might correspond to the origin of intercostal or visceral arteries. By pulsed Doppler imaging, flow velocities through the intimal tear reflect the pressure gradient between the two lumina. It is important to differentiate these secondary communications from the main intimal tear which usually has a diameter over 5 mm and is frequently located in the proximal part of the ascending aorta in type A dissections and immediately below the origin of the left subclavian artery in type B dissections. On occasions, 2D echocardiography does not permit visualization of the intimal tear in the proximal part of the arch. In these cases, contrast echocardiography may help by showing how contrast flows in the false lumen from the more proximal part of the aortic arch dissection.[48]

Table 3 Differentiation between true and false lumina

	True lumen	False lumen
Size	True < false	Most often: false > true lumen
Pulsation	Systolic expansion	Systolic compression
Flow direction	Systolic antegrade flow	Systolic antegrade flow reduced or absent, or retrograde flow
Communication flow	From true to false lumen in systole	
Contrast echo flow	Early and fast	Delayed and slow

True lumen identification

Identification of the true lumen is of special clinical interest. When the aortic arch is involved, the surgeon needs to know whether the supra-aortic vessels originate from the false lumen. Similarly, when the descending aorta dissection affects visceral arteries and ischaemic complications arise, it may be important to identify the false lumen prior to surgery or endovascular treatment such as intima fenestration or stent-graft implantation. Echocardiographic signs for differentiating the true lumen from the false lumen are summarized in *Table 3*.

Diagnosis of complications

Appropriate diagnosis of dissection complications during the initial study may affect therapeutic decisions in the acute phase.

Pericardial effusion and periaortic bleeding

Pericardial effusion is not always due to extravasation of blood from the aorta and may be secondary to irritation of the adventitia produced by the aortic haematoma or small effusion from the wall. In any event, the presence of pericardial effusion in an ascending aorta dissection is an indicator of poor prognosis and suggests rupture of the false lumen in the pericardium. Echocardiography is the best diagnostic technique for estimating the presence and severity of tamponade. Periaortic haematoma and pleural effusion are best diagnosed by CT. The presence of periaortic haematoma has been related to an increase in mortality.[47,55]

Aortic regurgitation

Aortic regurgitation is a frequent complication, occurring in ~40–76% of patients. The diagnosis and quantification of aortic regurgitation severity can be correctly made with Doppler echocardiography, both TTE and TOE. Furthermore, TOE provides information on possible mechanisms that influence aortic regurgitation, which may greatly aid the surgeon in deciding whether to replace the aortic valve[58] (*Table 4*).

Arterial vessel involvement

Diagnosis of involvement of the main arterial vessels of the aorta is important as it may explain some of the symptoms or visceral complications that accompany the dissection and permit selection of an appropriate therapeutic strategy. Involvement of coronary arteries in dissection has been considered to be 10–15%, with the right coronary artery being most frequently affected. Detection of segmental wall motion abnormalities of the left ventricle by TTE may help to identify this complication. In any event, left ventricular function assessment should be included in the TTE exam when acute aortic syndrome is suspected since some patients have previous left ventricular dysfunction secondary to hypertensive heart disease or other conditions. On the other hand, TOE shows the most proximal segment of the coronary arteries; thus, it can be verified whether the coronary ostium originates in the false lumen or whether coronary dissection is present. TOE is not a good technique for assessing supra-aortic branch involvement. However, in a recent work, sensitivity, specificity, and accuracy in the diagnosis of supra-aortic trunks were 60, 85, and 78%, respectively.[7] The origin of the left subclavian artery is easily observed. However, the origin of innominate or brachiocephalic trunk and left carotid arteries remains inconsistently detected. In these cases, the TTE suprasternal view appears very useful. TOE permitted the diagnosis of coeliac trunk involvement, dissection, or compression in most cases. Visceral or peripheral malperfusion syndrome is a complication with high morbidity and mortality. However, CT provides far more precise information and is irreplaceable for diagnosing renal and iliac artery disease. TOE, like CT, can diagnose two types of circulation disorders of arterial branches: dissection or dynamic obstruction of the intimal dissection at the ostium of the arterial branches leaving the aorta. Differentiating the two mechanisms has important therapeutic implications.[8]

Table 4 Mechanisms of significant aortic regurgitation in aortic dissection

Dilatation of the aortic annulus secondary to dilatation of the ascending aorta
Rupture of the annular support and tear in the implantation of one of the valvular leaflets
Asymmetrical dissections, the haematoma itself may displace a sigmoid below coaptation level
Prolapse of the intima in the outward tract of the left ventricle through the valvular orifice
Previous aortic valve disease

Recommendation

TOE should define the entry tear location, mechanisms and severity of aortic regurgitation, and true lumen compression. Pericardial effusion/tamponade and left ventricular function (global and segmental) may be assessed by TTE. In some specific complications, such as periaortic haematoma or involvement of the abdominal arterial trunks, additional information by CT or MRI is advisable.

Diagnosis of traumatic and iatrogenic aortic lesions

Blunt chest trauma may cause aortic rupture, dissection, or intramural haematoma. Rupture is due to a complete transection of the aorta where all three vascular layers are disrupted circumferentially. However, the adventitia may remain intact, or adjacent structures may contain the haemorrhage. A pseudoaneurysm then results, defined as disruption of at least one layer of the vessel wall and containment of rupture by the remaining layers and/or surrounding tissues. TOE has several advantages over other imaging methods in the evaluation of critically ill patients with trauma.[59] It can be performed quickly, at the bedside, without interrupting therapeutic measures. Nevertheless, it cannot be performed in patients with cervical spine fractures, which represent 5–25% of trauma victims.

Iatrogenic dissection of the aorta rarely occurs during heart catheterization. It is not infrequently seen following angioplasty of an aortic coarctation but can also be observed after cross-clamping of the aorta and after intra-aortic balloon pumping. Most catheter-induced dissections are retrograde dissections. Progression of the coronary dissection into the aortic root may be observed. Iatrogenic aortic trauma from vascular manipulation may cause dislodgement of debris from protruding or mobile atheromas. TOE may be the technique of choice for visualizing such lesions and assessing their embolic potential.

Recommendation

TOE should be considered a technique of choice when aortic complications are suspected after thoracic trauma since it is accurate, rapid, and can be performed at the bedside. Similarly, TOE is highly useful to rule out iatrogenic complications due to intravascular procedures.

Acute aortic syndrome prognosis and follow-up

Age, signs and/or symptoms of organ malperfusion and clinical instability, fluid extravasation into the pericardium, and periaortic

haematoma have poor prognosis in the acute phase.[55] Imaging techniques play an important role in identifying predictors of complications during follow-up.[60] The maximum aortic diameter in the subacute phase was a significant predictor of progressive dilatation. Other variables have been considered to have poor prognosis, such as compression of the true lumen[61] or partial false lumen thrombosis.[62] In contrast, a completely thrombosed false lumen showed a protective role.[55,62] Prognostic and therapeutic implications of TOE in aortic dissection are well established. Antegrade or retrograde false lumen flow, false lumen thrombosis, and the presence of communications have prognostic implications and are easily detected by TOE.[55] TOE has an important role in the follow-up of patients with aortic dissection as it shows the structure of the dissection, surgical repair, healing of the dissection and obliteration of the false lumen, or blood flow dynamics in true and false lumina. However, TOE is less useful than CT or MRI in the follow-up of aortic diameter dilatation, which is one of the predictors of worse prognosis.

The intramural haematoma can heal or evolve to aneurysm formation or even dissection.[63] In addition to maximal aortic diameter, some TOE information such as echolucent areas has been related to dissection and enlargement evolution.[61] The natural history of PAU is unknown. Like intramural haematomas, several evolutive possibilities have been proposed. As in other acute aortic syndromes, ascending aorta involvement carries a higher risk of severe complications than type B involvement. Both in intramural haematoma and aortic ulcer, CT and MRI with a larger field of view have some advantages in the follow-up of complications of these diseases.

Recommendation

Although TOE provides prognostic information on acute aortic syndrome evolution, particularly in aortic dissection, CT or MRI is more useful in the follow-up of arch and descending aorta diameters.

Intraoperative and post-operative echo

Echocardiography plays a crucial role in the pre-operative, intraoperative, and post-operative assessment of aortic diseases. Replacement by a composite graft (synthetic graft, valve mechanical prosthesis, and reimplantation of coronary arteries) has been considered the conventional treatment for patients with significant aortic incompetence caused by aortic root dilatation. Wall wrapping with stent-graft implantation has also been used as a treatment option. However, when the root is dilated but the leaflets are normal, valve-sparing root resection yields excellent results without the need to implant a prosthetic aortic valve. Knowledge of aortic root dimensions, aortic regurgitation severity and its mechanisms would enable pre-operative selection of the best surgical strategy and preparation of an adequately sized graft tube, repair or replacement of aortic valve, and shorten surgical ischaemia time. Previous studies have demonstrated that pre-operative measurement of aortic annular diameter by TTE and multiplane TOE is accurate and clinically feasible.

The important role of echocardiography in aortic valve repair lies in the recognition of the exact lesions that may be responsible for the insufficiency, and the selection of adequate operative manoeuvres to correct these abnormalities. TOE provides a highly accurate anatomical assessment of all types of aortic regurgitation lesions. In addition, the functional anatomy of aortic regurgitation defined by TOE is strongly and independently predictive of valve reparability and post-operative outcome.[41] The combination of functional evaluation by TOE and anatomical inspection at surgery is therefore paramount when assessing the suitability of the conditions for repair. By echocardiography, the tethering indices might have the potential to guide the planning of aortic valve-sparing surgery (see aortic aneurysm section). Accurate echocardiographic measurements of aortic root diameters are also essential in other types of surgery such as the Ross procedure, homograft aortic valves[64] or in percutaneous aortic valve implantation.[65,66]

Pre-operative or intraoperative TOE is essential for planning the surgical treatment of acute aortic syndrome and in deciding whether to replace the aortic valve[58] (see section on TOE) and can further be used to evaluate the placement of cannulae, assess perfusion in the different compartments of the aorta, and whether or not the true lumen has been perfused.[67] TOE may help to avoid early reoperations by showing the correct connection of the distal part of the graft tube to the true lumen, arch and supra-aortic vessel involvement, and the severity of residual aortic regurgitation. Finally, intraoperative TOE may detect complications such as pseudoaneurysm formation, most of which are secondary to a leak in coronary artery reimplantation to the graft tube, communication of the distal part of the tube to the false lumen, significant aortic regurgitation, periaortic haemorrhage, or segmental abnormalities in left ventricular contraction.

In cases where TOE cannot be performed intraoperatively, it should be attempted prior to extubation of the patient in the post-operative period for the early detection of complications.

Recommendation

Echocardiography is crucial in selecting and monitoring surgical treatment and detecting complications. Thus, intraoperative TOE should be considered mandatory. When intraoperative TOE has not been performed, the study should be made immediately after surgical treatment.

Endovascular therapy monitoring by intraoperative transoesophageal echocardiography

Intraoperative TOE is highly useful during endovascular therapy of the descending thoracic aorta, especially in type B aortic dissection, since it provides additional information to angiography/fluoroscopy for guiding correct stent-graft placement. For example, TOE is able to detect peri-stent leaks and/or small re-entry tears with much higher sensitivity than angiography.[68–72] In several publications, TOE provided decisive additional information to angiography/fluoroscopy, leading to successful procedural changes in up to 40–50% of patients.[70–72] TOE is useful in the operating theatre both before and after stent-graft deployment.

(1) Prior to stent-graft deployment in patients with type B aortic dissection, TOE is useful for guidewire repositioning (not possible with fluoroscopy) from the false to the true lumen and for

correct guidewire entrance into elephant trunk prostheses in patients with previous aortic arch surgery. In atherosclerotic aneurysms, protruding aortic plaques at the proximal neck may impede tight adhesion between the stent-graft and aortic wall, leading to dangerous proximal leaks. These plaques are usually detected by TOE and not by angiography/fluoroscopy. Therefore, just prior to proximal stent-graft deployment, TOE is essential for selecting an aortic wall segment without protruding plaques and confirming selection of the stent-graft diameter.

(2) After stent-graft deployment, colour-Doppler TOE is highly useful for detecting peri-stent leaks which can be promptly resolved by balloon dilatation or further stent-graft implantations. Most of these leaks are not usually visible on angiography. In aortic dissection, TOE is also useful for detecting small distal re-entry tears not visible on angiography; thoracic re-entry tears can subsequently be resolved by additional stent-graft deployment.

TOE has some limitations: (i) TOE is not able to guide abdominal endovascular procedures. In these treatments, conventional IVUS or intraluminal phased-array ultrasound imaging (IPAI) can be used. In a recent small study, IPAI proved to be superior to IVUS and to TOE in detecting communications between the true and false lumina of aortic dissection.[73] However, IVUS and IPAI are disposable and therefore more expensive than TOE; (ii) TOE is partially limited for visualizing the innominate and left carotid artery ostia, and this information may be crucial to proximal positioning of the stent graft; and (iii) TOE is useful when a Dacron stent graft is used, whereas it is not useful with PTFE (gore-tex) prostheses since PTFE acts as a barrier to ultrasound.

Recommendation

Intraoperative TOE is highly useful during endovascular treatment, particularly in descending aortic dissections. It permits correct guidewire entrance by identifying the true lumen in aortic dissections, provides additional information helpful to guide correct stent-graft positioning, and identifies suboptimal results and the presence of leaks and/or small re-entry tears, with much higher sensitivity than angiography.

Conflict of interest: none declared.

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