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Echocardiography 3314

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section 16 Cardiovascular disorders 3314 FURTHER READING Bruce, RA, Fisher LD (1987). Exercise-enhanced assessment of risk factors for coronary heart disease in healthy men. *J Electrocardiol*, 20 (Suppl. October), 162. Cura FA, et al. (2004). ST segment resolution 60 minutes after combination treatment of abciximab with reteplase or reteplase alone for acute myocardial infarction (30-day mortality results from the resolution of ST segment after reperfusion therapy substudy). *Am J Cardiol*, 94, 859-63. Einthoven W (1912). The different forms of the human electrocardiogram and their signification. *Lancet*, 1, 853-61. Gianrossi R, et al. (1989). Exercise-induced ST segment depression in the diagnosis of coronary artery disease: a meta-analysis. *Circulation*, 80, 87-98. Hancock EW, et al. (2009). AHA/ACCF/HRS recommendations for the standardization and interpretation of the electrocardiogram: part V: electrocardiogram changes associated with cardiac chamber hypertrophy. *J Am Coll Cardiol*, 53, 992-1002. Houghton AR, Gray D (2014). *Making sense of the ECG*, 4th edition. Hodder Arnold, London. Joint European Society of Cardiology/American College of Cardiology Committee (2000). Myocardial infarction redefined—a consensus document of the joint European Society of Cardiology/American College of Cardiology

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16.3.2 Echocardiography

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ESSENTIALS Ease of use, rapid data provision, portability, and safety mean that echocardiography has become the principal investigation for almost all cardiac conditions. A modern transthoracic echocardiography examination combines real-time two-dimensional imaging of the myocardium and valves with information about velocity and direction of blood flow obtained by Doppler and colour-flow mapping. A complete examination can be performed in most patients in less than 30 min. Valvular heart disease—echocardiography has revolutionized the diagnosis and follow-up of patients with these conditions. Serial cardiac catheterization to assess severity and progress of valvular stenosis has been completely superseded by Doppler echocardiography, and the role of invasive investigation is increasingly limited to the assessment of the coronary arteries prior to revascularization. Transoesophageal echocardiography—this is now a routine investigation in many centres. Under sedation, an ultrasound probe is passed into the oesophagus to a position behind the heart, producing excellent resolution of cardiac structures. It is used diagnostically in many emergency situations, including aortic dissection and suspected prosthetic mechanical valve dysfunction, and as an additional method of monitoring cardiac performance during cardiac and noncardiac surgery. Other technological developments—these include (1) stress echocardiography—used to detect occult coronary disease and predict cardiac risk; (2) use of contrast agents—these improve visualization of the endocardium in patients with poor acoustic

windows and allow some estimation of myocardial perfusion; and (3) real-time three-dimensional imaging—this is available on modern platforms and allows detailed assessment of myocardial and valve function. Recent developments in assessing myocardial mechanics by quantifying strain offer new insights into early pathological changes, and progressive miniaturization of platforms including fully portable systems have further increased the utility of echocardiography in the assessment of cardiac structure and function.

16.3.2 Echocardiography 3315 History of echocardiography The timeline of key discoveries and inventions is as follows: • 1842—Christian Doppler observed that the pitch of a sound varies if the source is moving. • 1880—first piezoelectric crystals developed. • 1912—Richardson develops sonar technique using sound waves to detect underwater objects. • 1929—Sokolov uses ultrasound to identify flaws in metal components. • 1954—heart visualized with ultrasound by Carl Herz and Inge Edler. • 1960s—multielement scanners lead to development of two-dimensional (2D) echocardiography. • 1970s—Doppler colour-flow mapping used to evaluate valve disease. • 1970s—transoesophageal and stress echocardiography developed. • 1980s—ultrasound contrast agents developed. • 1990s—intracardiac and intracoronary ultrasound in wider use. • 2000s—development and refinement of three-dimensional (3D) echocardiography and advances in myocardial deformation imaging.

Principles of echocardiography The transducer used for most echocardiographic examinations contains piezoelectric crystals that emit ultrasound frequencies of 2.5–5 MHz. Most of the sound energy is scattered or absorbed, but reflection occurs at interfaces between tissues of different acoustic impedance (e.g. between blood and muscle). The transducer collects these reflections and the time delay between emission and reception is calculated. This allows the depth of the reflection to be derived and its position to be displayed on a screen as a dot (pixel). The brightness of the dot is related to the magnitude of the reflected signal. In general, higher-frequency transducers allow better discrimination between structures, but the increased attenuation leads to reduced penetration. There are three main echocardiographic techniques: two-dimensional (cross-sectional), M-mode, and Doppler.

Two-dimensional echocardiography (cross-sectional) Cross-sectional images are constructed as the ultrasound beam sweeps across the heart in a sector (Fig. 16.3.2.1). Between 50 and 100 cross-sections are presented each second, giving the impression of a moving picture. These images are readily interpretable by an observer with knowledge of cardiac anatomy, and this technique is the cornerstone of modern echocardiography.

M-mode echocardiography M-mode echocardiography preceded modern 2D imaging. Unlike 2D imaging, which uses a series of sweeps across the heart, M-mode uses a single static beam of ultrasound pulses at a very high frequency. The narrow beam is analogous to a vertical mineshaft passing through various layers of rock. Displayed in real time, this results in reflections from cardiac structures being displayed as horizontal lines, with superficial structures at the top of the screen and the deeper structures at the bottom (Fig. 16.3.2.2). These data are interpretable when one knows which structure each line represents. The technique has excellent spatial resolution and temporal resolution; hence, with the advent of 2D echocardiography and Doppler, M-mode is now principally used for measurement of cardiac chamber dimensions and observation of the relative movement of cardiac structures to each other; for example, the relationship of the anterior leaflet of the mitral valve to the septum in hypertrophic cardiomyopathy.

Doppler echocardiography The Doppler principle allows the velocity and direction of movement of an object (blood or myocardium in the case of cardiac ultrasonography) to be calculated from the shift in the frequency of a reflected waveform relative to the observer. Cardiac imaging employs pulsed-wave, continuous-wave, and colour Doppler techniques. Pulsed-wave

Doppler allows information about flow to be obtained from a defined point within the heart. The range of detectable velocities is limited, and the technique is used for sampling normal and low velocities (e.g. mitral valve flow). Fig. 16.3.2.1 Parasternal long-axis view of the heart using 2D echocardiography. The sector images through the right ventricle (RV) to the left ventricle (LV). In this view, 2D echocardiography provides useful data on the structure and function of the aortic valve (AV) and mitral valve (MV). Fig. 16.3.2.2 M-Mode view of the left ventricle. The high imaging frequency of M-mode allows accurate measurements of structures to be made, in this case the diastolic (D) and systolic (S) cavity size.

section 16 Cardiovascular disorders 3316 Continuous-wave Doppler identifies the peak velocity encountered along the whole of the ultrasound beam and is particularly valuable for measuring high-velocity jets such as those in aortic valve disease (Fig. 16.3.2.3). It is important to remember, however, that failure to align the transducer exactly parallel to flow results in measurement of artefactual low velocities and potentially an underestimation of valvular stenosis. Colour Doppler allows a dynamic representation of the direction and velocity of flow to be superimposed on to a 2D image of the heart. Velocities towards the transducer are usually coded in red and velocities away in blue (Fig. 16.3.2.4). Turbulent and high-velocity flow produces variable velocities and results in a mosaic pattern that is ideal for characterization of regurgitant lesions. This technique is now so sensitive that it can detect trivial regurgitation during the closure of many normal heart valves. Tissue Doppler echocardiography uses the same principles but by changing the settings the direction and velocity of the myocardium is encoded rather than the blood pool. Pulse-wave Doppler can then be used to interrogate a specific part of the myocardium and provide detailed information on myocardial mechanics in both systole and diastole (Fig. 16.3.2.5). Transthoracic echocardiography Imaging is performed using dedicated echocardiography equipment with the patient lying on their left hip in the left lateral position and with their left arm behind their head to open the rib spaces. Ultrasound cannot travel through bone and thus cardiac imaging is performed via intercostal spaces to the left of the sternum and at the apex of the heart in the axillary line. These 'echo windows' provide standard views described as the parasternal short and long axis and apical two-, four-, and five-chamber views. Useful additional views can also be obtained from the subcostal and suprasternal approach in some patients. A standard echocardiography examination involves 2D imaging from the parasternal, apical, and subcostal approaches supported by M-mode measurements, continuous, pulsed, and colour Doppler and tissue Doppler imaging. Valvular heart disease Transthoracic echocardiography is the investigation of choice for patients with suspected valvular heart disease. All four cardiac valves can be visualized and interrogated by Doppler and 2D echocardiography. Concomitant abnormalities in ventricular performance can be assessed simultaneously. Aortic stenosis Two-dimensional echocardiography can usually image the aortic valve cusps; if they are thin and freely mobile, it is unlikely that there is significant aortic stenosis. However, if the valve cusps are thickened and calcified, interrogation by continuous-wave Doppler is mandatory. The severity of aortic stenosis is usually expressed as the peak pressure difference (or gradient) across the valve, and is calculated from the maximum flow velocity (V) using the modified Bernoulli equation ($\text{pressure gradient} = 4V^2$). In patients with normal left ventricular systolic function, a peak gradient measured by Doppler of over 65 mm Hg or a mean gradient of over 40 mm Hg suggests significant aortic stenosis. The aortic valve area can be estimated using the continuity equation which requires measurement of the left ventricular outflow tract diameter on 2D echo and Fig. 16.3.2.3 Continuous-wave Doppler of the aortic valve showing aortic regurgitation (flow towards the probe above the line). Calculations can be

performed using on-machine software to instantly provide useful haemodynamic data. Fig. 16.3.2.4 Colour-flow mapping of mitral regurgitation. There is high-velocity flow in systole from the left ventricle into the left atrium through the mitral valve. Fig. 16.3.2.5 Tissue Doppler of the basal interventricular septum allowing measurement of the systolic contraction (S) and early passive relaxation (E') phase.

16.3.2 Echocardiography 3317 the velocity at this point using pulse-wave Doppler (Fig. 16.3.2.6). Severe stenosis usually equates to a valve area of less than 1.0 cm² but should be indexed to the patient's body surface area. When chronic critical outflow obstruction results in declining left ventricular function and reduced cardiac output, the gradient produced by any degree of valve obstruction also falls. Doubt about the severity of the stenosis can usually be resolved by enhancing left ventricular function by administering intravenous dobutamine and evaluating the gradient during increased flow. Aortic regurgitation Assessment of the mechanism and severity of aortic regurgitation requires a combination of all three echocardiography modalities. M-mode may demonstrate fluttering of the anterior leaflet of the mitral valve and, in the setting of acute severe aortic regurgitation, may reveal premature closure of the mitral valve. Two-dimensional echocardiography will occasionally demonstrate prolapse of one more of the aortic cusps, but even severe aortic regurgitation can occur through an aortic valve that appears to be structurally normal. The severity of aortic regurgitation can be estimated using continuous-wave and colour Doppler (see Chapter 16.6, Figs. 16.14.1.3 and 16.14.1.4), although assessment can be difficult as it is influenced by left ventricular function and blood pressure. Doppler-derived pressure half-time and measurement of regurgitant fraction and/or flow convergence zone are valuable when there is uncertainty over lesion severity. M-mode and colour Doppler can be combined and, when the regurgitant jet fills more than 50% of the left ventricular outflow tract, the regurgitation is classified as severe. Flow within the descending thoracic aorta can be measured using pulse-wave Doppler and in severe aortic regurgitation there is typically holodiastolic flow reversal—analogueous to the collapsing pulse. In patients with severe asymptomatic aortic regurgitation, serial increase in left ventricular dimensions or a progressive fall in ejection fraction are indications for surgery. However, any increase in ventricular dimension should be at least 0.5 cm before it is regarded as significant, given the limited reproducibility of echocardiographic parameters. Mitral stenosis Mitral valve stenosis is well visualized using either M-mode or cross-sectional echocardiography. Its severity can be determined by estimating the area of the valve orifice either by direct planimetry on a 2D short-axis image or from the Doppler pressure half-time (mitral valve area = 220/pressure half-time). A valve area of less than 1.0 cm² usually indicates severe mitral stenosis (Fig. 16.3.2.7). The mean gradient across the valve can also be measured by Doppler and is typically more than 10 mm Hg in severe stenosis. Transthoracic echocardiography is also used to assess the suitability of the mitral valve for balloon dilation, although transoesophageal imaging is necessary to exclude left atrial thrombus. Mitral regurgitation Transthoracic echocardiography will usually demonstrate the mechanism and severity of mitral regurgitation. Two-dimensional imaging identifies abnormalities of the valve leaflets and colour-flow shows jet direction and area (Fig. 16.3.2.8). Severe mitral regurgitation is suggested by increased left ventricular end-diastolic dimension and hyperdynamic function due to volume overload. Fig. 16.3.2.6 Continuous-wave Doppler through the aortic valve. The peak velocity is 503 cm/s. This equates to a peak pressure gradient (A0 max PG) of 101 mm Hg. Previous measurements of the left ventricular outflow tract diameter and velocity allow a calculated aortic valve area to be derived, in this case 0.57 cm². Fig. 16.3.2.7 Pulse-wave Doppler at the mitral valve leaflet tips in a patient with severe mitral valve

stenosis. The pressure half-time is calculated as 368 ms, giving an estimated valve area of 0.6 cm². Fig. 16.3.2.8 Apical four-chamber view with colour-flow demonstrating an eccentric jet of mitral regurgitation from the left ventricle (LV) to the left atrium (LA). In this case, the leak is due to prolapse of the posterior mitral valve leaflet.

section 16 Cardiovascular disorders 3318 Precise quantification of the amount of regurgitation is demanding as it is influenced by left ventricular function, the direction of the jet, and left atrial size. Various algorithms have been devised to improve quantification of mitral regurgitation, including measurement of the flow convergence zone and the proximal isovelocity surface area (PISA) method, but most centres simply classify the extent of regurgitation as mild, moderate, or severe (Table 16.3.2.1). Pulmonary and tricuspid valve disease In adults, 2D imaging of the pulmonary valve may be difficult, particularly if there is lung disease. Despite this, accurate Doppler information is usually obtainable. Tricuspid stenosis is very uncommon, but some degree of tricuspid regurgitation is detectable even in healthy individuals. Measurement of the peak velocity of tricuspid regurgitation (V) is valuable as, in the absence of pulmonary valve disease, it can be used to estimate pulmonary artery (PA) systolic pressure: PA systolic pressure (mm Hg) = $4V^2$ + right atrial pressure

(usually 5–10 mm Hg). Prosthetic valves Transthoracic echocardiography is commonly performed as part of the routine follow-up of prosthetic valves. It is usually able to assess biological valves accurately, but for mechanical mitral valve prostheses, attenuation artefact produced by the metal may be problematic. Transoesophageal imaging is recommended when transthoracic imaging is suboptimal or if improved resolution is required, for example, in patients with suspected prosthetic valve endocarditis. Haemodynamic assessment Using Doppler to evaluate flow across all four cardiac valves and the great vessels, the pressure within each cardiac chamber can be estimated and a comprehensive description of the current haemodynamic status provided (Fig. 16.3.2.9). This can be extremely helpful in the setting of intensive cardiorespiratory support, although obtaining clear and accurate images in critically ill patients can be very challenging. Abnormal left ventricular function In most patients, a full transthoracic echocardiography study will confirm or refute a clinical suspicion of left ventricular dysfunction and identify the likely aetiology of any abnormality. Systolic and diastolic left ventricular function can be assessed, and a variety of methods can be used to derive an estimate of left ventricular ejection fraction. The most accurate methods use imaging in two orthogonal planes or a 3D technique to model the whole left ventricle (Fig. 16.3.2.10). The normal ejection fraction (calculated from the end-diastolic and end-systolic volumes) is greater than 55%. An ejection fraction of 45–54% equates to mild left ventricular dysfunction, 30–44% to moderate dysfunction, and less than 30% to severe dysfunction. However, ejection fraction as a single measure of systolic function can be misleading as it is influenced by both preload and afterload, and can be preserved even with significant myocardial pathology. Advances in image processing have facilitated the advent of speckle tracking, whereby unique patterns of ultrasound reflections within the myocardium are tracked frame by frame and used to derive measures of myocardial deformation. The most robust of these is global longitudinal strain, with a value of -20% being considered normal and abnormal values being closer to 0%. There is emerging evidence that this parameter changes before ejection fraction and is more reproducible. In patients with ischaemic heart disease, assessment of regional wall motion is valuable. Segments may be described as normokinetic, hypokinetic, akinetic, dyskinetic, or aneurysmal. Detection of a regional wall motion abnormality in patients presenting with left ventricular systolic

dysfunction supports an ischaemic aetiology. The echocardiographic assessment of diastolic dysfunction is complex, but increasingly important in the assessment of patients with heart failure presenting with a normal ejection fraction. Impaired diastolic filling is indicated by a combination of echocardiographic findings routinely measured. Measurements of early Table 16.3.2.1
 Classification of mitral regurgitation Mild Severe Specific signs of severity Vena contracta <0.3 cm

“ 0.7 cm Jet size <4 cm² or <20% left atrium 40% left atrium Small and central Large and central or wall-impinging and swirling PISA radius None/minimal (<0.4 cm) Large (>1 cm) Pulmonary vein flow Systolic reversal Valve structure Flail or rupture Supportive signs of severity Pulmonary vein flow Systolic dominant Mitral inflow A-wave dominant E-wave dominant (>1.2 m/s) CW trace Soft and parabolic Dense and triangular LV and LA Normal size LV if chronic MR Enlarged LV and LA if no other cause CW, continuous wave; LA, left atrium; LV, left ventricle; PISA, proximal isovelocity surface area.

16.3.2 Echocardiography 3319 Fig. 16.3.2.9 An example of the haemodynamic parameters that can be estimated with a standard transthoracic echocardiography data set. Fig. 16.3.2.10 Apical four-chamber and two-chamber views in end diastole and end systole with an overall ejection fraction derived from the change in volume.

section 16 Cardiovascular disorders 3320 diastolic filling E (the peak early diastolic flow velocity) compared to that associated with atrial filling (A) giving an E/A ratio greater than 1.0 are often used as an indicator of diastolic dysfunction but rely on the patient being in sinus rhythm and can be misleading in severe diastolic dysfunction where pseudo normalization may occur. The ratio of tissue Doppler measurement of peak early diastolic mitral annular tissue velocities (e') in combination with peak early diastolic filling (E) providing a ratio (E/e') is also used as an indicator of diastolic dysfunction. A ratio greater than 15 is strongly supportive of diastolic dysfunction. The presence of an enlarged left atrium is an important discriminator as left atrial size is rarely normal in the presence of significant diastolic dysfunction. These parameters are often abnormal in older people and only support a diagnosis of diastolic heart failure in conjunction with appropriate clinical features. Pulmonary artery pressure Estimation of pulmonary artery pressure from a tricuspid regurgitant jet is possible in most echocardiographic examinations (see earlier). Causes of an elevated pulmonary artery systolic pressure (>35 mm Hg) include left heart failure, valvular disease (particularly mitral valve disease), pulmonary embolic disease, chronic obstructive airways disease, and pulmonary vascular disease. Left ventricular hypertrophy Left ventricular hypertrophy is detected by echocardiography and a measurement of left ventricular mass can also be derived. Transthoracic echocardiography may also detect intracardiac thrombus, particularly in patients with impaired systolic ventricular function (Fig. 16.3.2.11). Minor concentric left ventricular hypertrophy is common in patients with hypertension. In hypertrophic cardiomyopathy, 2D imaging may demonstrate asymmetrical septal hypertrophy with disproportionate thickening of the interventricular septum compared with the left ventricular free wall, or dramatic concentric hypertrophy with left ventricular cavity obliteration. Other characteristic features of hypertrophic cardiomyopathy include systolic anterior motion of the mitral valve and partial midsystolic closure of the aortic valve, which usually correlates with the presence of outflow tract obstruction. In the

absence of conditions that may induce ventricular hypertrophy (e.g. aortic stenosis), these findings are diagnostic of hypertrophic cardiomyopathy. Colour Doppler can demonstrate turbulence in the outflow tract and continuous-wave Doppler may detect characteristic 'dynamic' gradients that increase in severity as systole progresses. Other associated echocardiographic abnormalities in hypertrophic cardiomyopathy include mitral regurgitation and severe diastolic dysfunction. Atrial fibrillation Most patients with atrial fibrillation should undergo echocardiography as it excludes a structural cause for atrial fibrillation (e.g. mitral stenosis) and facilitates thromboembolic risk stratification. It also allows measurement of left atrial dimensions, which can guide treatment as the success of cardioversion falls as the left atrium enlarges. Identification of left ventricular hypertrophy can guide the choice of antiarrhythmic drug therapy.

Transoesophageal echocardiography can be useful to facilitate cardioversion in patients with atrial fibrillation of unknown duration by excluding intracardiac thrombus, particularly in the left atrial appendage (Fig. 16.3.2.12). Following an embolic event or stroke Echocardiography is the investigation of choice when a cardiac source of an embolus is suspected. It should be considered in all patients presenting with embolic occlusion of a peripheral artery, or thromboembolic episodes in more than one vascular territory. Echocardiography should not, however, be performed in circumstances when the result is unlikely to influence patient management. In patients with ischaemic stroke and a low likelihood of atheromatous arterial disease, an echocardiogram can be considered as, occasionally, it will detect occult abnormalities such as a cardiac thrombus or atrial myxoma (Fig. 16.3.2.13). Enhancement of the right heart with nontranspulmonary contrast such as agitated saline should be considered to exclude paradoxical embolism through a cardiac shunt, and include Valsalva manoeuvres Fig. 16.3.2.11 Apical four-chamber view showing the left ventricle (LV), left atrium (LA), right ventricle (RV), and right atrium (RA). There is a large thrombus attached to the left ventricular apical septum. Fig. 16.3.2.12 Transoesophageal echocardiography of a patient with atrial fibrillation. There is a large thrombus filling (and extending from) the left atrial appendage (LAA). LA, left atrium; LV, left ventricle.

16.3.2 Echocardiography 3321 to augment any right to left shunt. In patients with a high clinical suspicion of a cardiac source of embolus, in whom transthoracic echocardiography is normal, transoesophageal echocardiography is recommended. Pericardial disease Echocardiography is not routinely indicated in patients with uncomplicated pericarditis. It can, however, diagnose the presence of pericardial fluid and is useful when a pericardial effusion is suspected and percutaneous drainage is being considered. Echocardiographic signs of pericardial tamponade include exaggerated respiratory variation in the mitral valve Doppler, presystolic closure of the aortic valve, and (particularly) right atrial and right ventricular diastolic collapse (Fig. 16.3.2.14). Constrictive pericarditis is a difficult diagnosis to make using standard echocardiographic techniques. Patients may complain of episodic breathlessness and fluid retention, have characteristic abnormalities of the venous pressure, and have subtle abnormalities on mitral and tricuspid valve inflow Doppler patterns. Pulmonary embolism Echocardiography can be useful in patients with pulmonary embolism as it can demonstrate right ventricular dilation and/or impaired right ventricular systolic function. Tricuspid regurgitant velocity can be used to estimate pulmonary artery systolic pressure, although it is unusual for this to be more than 70 mm Hg acutely. Exceptionally, 2D imaging may show a thrombus within the right heart or the proximal pulmonary arteries. Although echocardiography is diagnostically useful when it demonstrates features consistent with pulmonary embolism, it cannot exclude the diagnosis. Infective endocarditis Echocardiography cannot be used to exclude endocarditis but is valuable when endocarditis is

suspected clinically while there is insufficient data to make a formal diagnosis. Under these circumstances, a typical vegetation (Fig. 16.3.2.15) detected by an experienced observer is regarded as a major criterion in the Duke diagnostic classification, and this may facilitate appropriate management. Transoesophageal echocardiography should be performed when there is a suspicion of aortic root abscess, if prosthetic endocarditis is suspected, or occasionally, in cases where there is persistent diagnostic doubt and the additional sensitivity and spatial resolution of transoesophageal echocardiography might be valuable. Congenital heart disease Echocardiography is the diagnostic modality of choice for patients with suspected congenital heart disease. Detailed transthoracic cardiac imaging is possible in cooperative infants and children, but occasionally sedation or a short anaesthetic may be required. Rates of cardiac catheterization have been reduced by miniaturization of transoesophageal probes that facilitate diagnosis and follow-up of complex congenital heart disease. Fetal echocardiography is performed when surveillance obstetric ultrasound is abnormal, or in cases where previous history suggests a possible cardiac problem.

Fig. 16.3.2.13 Transoesophageal echocardiography revealing a large myxoma in the left atrium (LA) and close to the mitral valve. Fig. 16.3.2.14 Apical four-chamber view demonstrating a large pericardial effusion. There is collapse of the right ventricle, suggesting cardiac tamponade. Fig. 16.3.2.15 Apical four-chamber view demonstrating a large vegetation involving the mitral valve.

section 16 Cardiovascular disorders 3322 Transoesophageal echocardiography Transoesophageal echocardiography is now available in many centres (Fig. 16.3.2.16). The ultrasound probe is like an endoscope used for upper gastrointestinal investigation, except that there are no optical fibres. Transoesophageal echocardiography is an invasive procedure for which the patient's written consent is (usually) required. After fasting for a minimum of 4 h, a local anaesthetic spray (10% lidocaine) is applied to the upper pharynx and the patient is usually sedated, typically with a short-acting intravenous benzodiazepine (e.g. midazolam 2 mg). The probe is manipulated into the oesophagus where its position behind the heart produces excellent resolution, particularly of posterior cardiac structures. Blood pressure and oxygen saturation are monitored throughout, and both resuscitation equipment and the benzodiazepine antagonist flumazenil should be readily available. Even though transoesophageal echocardiography is commonly performed in high-risk, haemodynamically unstable patients, the rate of serious complications (aspiration and oesophageal rupture/ tears) is less than 1%. Absolute contraindications to transoesophageal echocardiography include oesophageal tumours, strictures, diverticula, and varices. Who should have a transoesophageal

echocardiogram? The indications for transoesophageal echocardiography are listed in Box 16.3.2.1. The principal advantages over transthoracic imaging are improved spatial resolution and the ability to image posterior structures such as the left atrium and descending aorta. It is valuable in many emergency situations, including suspected aortic dissection, prosthetic mechanical valve failure, and possible endocarditis. Transoesophageal echocardiography may be used to image the heart in patients in whom data from transthoracic imaging is unsatisfactory due to obesity, lung disease, or chest deformity. Other indications include screening for left atrial thrombus before cardioversion of atrial fibrillation, and monitoring cardiac performance during cardiac and some non-cardiac surgery. Valve disease Patients with mitral stenosis are at increased risk of thromboembolism, and transthoracic echocardiography has limited sensitivity for the detection of left atrial thrombus. Transoesophageal echocardiography is recommended in those patients with mitral stenosis if embolic events occur despite therapeutic anticoagulation, and may demonstrate

spontaneous echocardiography contrast (smoke-like echoes produced by the interaction of erythrocytes and plasma proteins under conditions of stasis). This is an independent predictor of left atrial thrombus and cardiac thromboembolic events. Transoesophageal echocardiography is also used to assess anatomy and exclude left atrial thrombus before balloon valvuloplasty in patients with mitral stenosis and to assess anatomy, severity, and suitability for surgical repair in patients with mitral regurgitation. In patients with mitral prostheses, reverberation artefact overlying the left atrium limits the ability of transthoracic imaging to detect paraprosthetic regurgitation. Transoesophageal imaging provides excellent visualization of the left atrium and is particularly recommended under these circumstances. Endocarditis Characteristic vegetations or evidence of abscess formation identified by echocardiography are increasingly used as diagnostic criteria in patients with possible endocarditis. The excellent spatial resolution (<1 mm) of transoesophageal echocardiography Fig. 16.3.2.16 Transoesophageal echocardiography. Box 16.3.2.1 Principal indications for transoesophageal echocardiography

- Valve disease
- Mitral stenosis—to assess suitability for percutaneous balloon commissurotomy and exclude left atrial thrombus
- Mitral regurgitation—to assess anatomy, severity, and suitability for surgical repair
- Prosthetic valves—particularly to assess prosthetic mitral regurgitation
- Infective endocarditis
- Possible aortic root abscess
- Failure to respond to antibiotics, or recurrent fever in a patient with endocarditis
- High clinical suspicion of endocarditis with no diagnostic abnormality on transthoracic imaging
- Possible prosthetic valve endocarditis
- Aortic disease
- Possible acute aortic dissection
- Follow-up of patients with known aortic pathology
- Imaging aortic atheroma before surgery or patients with possible cholesterol embolization
- Potential cardiac source of embolism
- Before elective cardioversion of atrial fibrillation
- Patients with valvular heart disease and a definite embolic episode despite anticoagulation
- Patients with a definite embolic episode and a 'normal heart' on transthoracic imaging
- Incomplete or impractical transthoracic imaging
- Chest deformity or pulmonary disease
- Patients undergoing mechanical ventilation
- Congenital heart disease
- Perioperative imaging of cardiac function and surgical procedures

16.3.2 Echocardiography 3323 makes it superior to transthoracic imaging for the detection of vegetations and its sensitivity may exceed 90% (Fig. 16.3.2.17). Transoesophageal echocardiography should be considered when there is a high clinical suspicion of endocarditis but blood cultures are sterile and transthoracic imaging is not diagnostic, or under circumstances when the sensitivity of transthoracic imaging is particularly poor, for example, prosthetic valves or calcific valvular disease. Transoesophageal echocardiography is also recommended if there is a possibility of aortic root abscess formation, as this complication is not easily identified using transthoracic imaging and surgery may be required. Aortic disease Transthoracic imaging of the aorta is limited to the proximal aortic root and the arch in most patients. Using transoesophageal imaging, most of the ascending and the entire descending thoracic aorta can be visualized and image quality is improved. This is particularly useful in patients with suspected acute aortic dissection and, in many cases, it is the only imaging necessary before emergency surgery (see Chapter 16.14.1, Figs. 16.14.1.8 and 16.14.1.9). Large, mobile, or pedunculated aortic atheromas in the descending aorta which can be associated with ischaemic stroke may be detected by transoesophageal echocardiography (Fig. 16.3.2.18). Transoesophageal imaging of the aorta has also been recommended in suspected cases of cholesterol embolization and to assess thromboembolic risk prior to cardiac intervention or surgery. Thromboembolism In patients with thromboembolism, there has been extensive debate over the value of imaging with transoesophageal echocardiography. Clinical examination, electrocardiography, and transthoracic

echo-cardiography provide sufficient information to determine optimal management in the majority. However, transoesophageal echocardiography is indicated when embolic events occur in anticoagulated patients with native or prosthetic valvular heart disease, especially if endocarditis is suspected, or when transthoracic images are inconclusive. In patients with unexplained or cryptogenic ischaemic stroke, wider use of transoesophageal echocardiography has been advocated. Transthoracic echocardiography and exclusion of alternative pathologies such as thrombophilia and carotid stenosis should precede the transoesophageal examination, but under these circumstances minor cardiac structural abnormalities are more likely to be clinically relevant. Transoesophageal echocardiography is superior to the transthoracic approach for imaging the interatrial septum for atrial septal aneurysm (a redundant bulge in the fossa ovale, with respiratory movement >10 mm) and assessing patency of the foramen ovale (Fig. 16.3.2.19). However, the clinical relevance of such atrial septal abnormalities can be questionable as the relationship to the thromboembolic event is commonly speculative. Currently, anticoagulation is the usual management following an otherwise unexplained, single, embolic event, but occasionally percutaneous or surgical correction of the defect is recommended. Fig. 16.3.2.17

Transoesophageal echocardiography demonstrating a large vegetation attached to the mitral valve. LA, left atrium; LV, left ventricle. Fig. 16.3.2.18 Transoesophageal echocardiography of the descending aorta (AO). There is a prominent, eccentric, and mobile atherosclerotic plaque.

Fig. 16.3.2.19 Transoesophageal echocardiography of the interatrial septum. The flap of the patent foramen ovale can be seen where the septum primum is overlapped by the septum secundum. There is colour-flow through it (arrowed) from the left atrium (LA) to the right atrium (RA).

section 16 Cardiovascular disorders 3324 Stress echocardiography Diagnosis of reversible ischaemic myocardial dysfunction is now possible using echocardiography. Imaging can be performed either during or immediately after exercise, but more commonly an intravenous infusion of dobutamine is used to mimic the cardiac response to exercise. Development of reversible systolic regional wall motion abnormalities suggests coronary artery disease. Stress echocardiography also has an increasing role in risk stratification before general surgical procedures and in assessing myocardial viability before revascularization. The use of transpulmonary contrast agents to opacify the left ventricle and enhance endocardial definition greatly reduces the number of inconclusive scans, allowing more accurate assessment of left ventricular function and some measure of myocardial perfusion (Fig. 16.3.2.20). Intracardiac echocardiography Miniaturization of echocardiography probes has led to the development of echocardiography from within the heart. Small, flexible catheters with ultrasound transducers (Fig. 16.3.2.21) can be manoeuvred within the heart to provide very high-resolution images of intracardiac structures. This has been particularly useful during percutaneous closure of atrial septal defects and during radiofrequency ablation procedures (Fig. 16.3.2.22). Three-dimensional echocardiography Real-time, 3D image acquisitions with both transthoracic and transoesophageal echocardiography are now available on most high-end echocardiography machines. Some systems acquire a series of gated images to reconstruct the entire heart during a cardiac cycle. This image can then be manoeuvred and slices cut away to visualize the area of interest (Fig. 16.3.2.23). Regional wall tracking can also allow a 3D model of left ventricular function to be acquired and provides Fig. 16.3.2.20 A sequence of apical two-chamber images during a stress echo. At peak stress a wall motion abnormality in the inferior apex is evident, which persists into the recovery phase. Fig. 16.3.2.21 Comparison of an intracardiac echocardiography probe with a standard transoesophageal echocardiography probe with a close-up view of the tip of the probes.

The intracardiac probes are for single use only; the transoesophageal probes are sterilized after each procedure. Fig. 16.3.2.22 Intracardiac echocardiography from the right atrium (RA). An atrial septal defect is being closed using a percutaneous approach. The disc in the left atrium (LA) has been deployed and is about to be pulled tight to the interatrial septum. Fig. 16.3.2.23 3D transoesophageal echocardiography of the mitral valve. The images show prolapse of the central portion of the posterior leaflet with three ruptured chordae. The whole of the mitral valve is in view and oriented to mimic the view of the cardiac surgeon at the time of mitral valve repair.

16.3.2 Echocardiography 3325 an accurate assessment of left ventricular function (Fig. 16.3.2.24) as well as identifying areas of left ventricular dys-synchrony. Transthoracic 3D acquisition is limited by frame rate and image quality in the same way as 2D echocardiography. Transoesophageal 3D echocardiography usually produces clear 3D images, particularly of the mitral valve and is excellent for examination of prosthetic mitral valves (Fig 16.3.2.25). It is particularly helpful in displaying and communicating pathology, as views familiar to cardiac surgeons can be recreated and displayed. Echocardiography in the emergency setting Echocardiography equipment increases in sophistication but also continues to miniaturize, and now several small portable ultrasound devices are available (Fig. 16.3.2.26). These are increasingly available in emergency and intensive care departments. A hand-held 'screening ultrasound' can be performed in a matter of seconds to exclude pericardial effusion, recognize left ventricular dysfunction Fig. 16.3.2.24 3D transthoracic echocardiography of the left ventricle. The whole of the left ventricle is captured over four cardiac cycles and stitched together to create a single volume of data. Corrections for foreshortening can be made, the volume traced over time, and a 3D 'model' of the left ventricle created with each segment shaded a different colour. Fig. 16.3.2.25 3D transthoracic echocardiography of a mechanical prosthetic mitral valve. The sutures placed by the surgeon are visible as a row of dots around the sewing ring. Fig. 16.3.2.26 Hand-carried ultrasound allows rapid assessment of cardiac function and can exclude a pericardial effusion.

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