What neurologists need to know about echocardiography

WHAT IS ECHOCARDIOGRAPHY?
Echocardiography evolved in the early 1950s, predominantly as a tool to help select patients for mitral valvotomy. Its pre-eminence in the 1990s arose from advances in microcomputing. These days the echocardiography machine is effectively a powerful computer, which uses ultrasound to image and map blood flow within the heart and great vessels.

Imaging
Most ultrasound entering the body is scattered or absorbed, but some is reflected back to the transducer at interfaces where the acoustic density of tissue changes. The two-dimensional echocardiographic image is therefore a map of the acoustic density of the heart, and it happens to resemble a pathological section. Two-dimensional imaging shows the anatomy and motion of the chambers and valves and can be used to measure wall thickness and cavity size (Fig. 1). The echocardiographer builds up a three-dimensional image in his or her head, and formulae making geometric assumptions can be used to estimate left ventricular volumes.

Doppler
If ultrasound is reflected from blood moving towards the probe, its wavelength is shortened. Conversely, if the blood is moving away, the wavelength is drawn out. The change between the wavelengths of the transmitted and returning ultrasound is computed to produce a graph of velocity against time (Fig. 2a). Continuous wave is the oldest Doppler modality and involves two crystals, one transmitting and the other receiving continuously. This technique is used to calculate the severity of stenotic valve lesions, to estimate pulmonary artery pressure and to provide a semiquantitative assessment of the grade of valvular regurgitation (Fig. 2a).

Pulsed Doppler (Fig. 2b) was introduced to record flow at a relatively focused region within the heart by incorporating a delay between transmission and recording to allow for the time taken for ultrasound to travel to and from the desired point. It is used to assess diastolic left ventricular function, and to calculate stroke volume, cardiac output and shunt size.

Colour flow mapping
This is an automated version of pulsed Doppler and is used to screen for valvular regurgitation, or for a shunt, and to give a semiquantitative estimate of valve regurgitation. The machine calculates mean blood velocity and direction of flow at multiple points down the ultrasound scan lines. Using colour-encoding, the velocity information is then superimposed onto the image (Fig. 3).

Figure 1 Aortic valve disease. This is a two-dimensional echocardiogram showing a heavily calcified and immobile aortic valve (arrow). The left ventricle is hypertrophied. Ao, aorta; LA, left atrium; LV, left ventricle.
now about outside neurology

Figure 2 Continuous wave and pulsed Doppler. (a) Continuous wave Doppler records all velocities in its path and produces effectively a graph of velocity on the y-axis (each marker represents 1 msec) against time on the x-axis (large bars indicate 100 msec). By convention, velocities towards the probe appear above the baseline and those away appear below the baseline. This example shows flow recorded with the transducer placed over the apex in a patient with dominant aortic stenosis and moderate aortic regurgitation (see also Fig. 1). Flow velocities during systole are elevated. There is also a regurgitant jet during diastole. The pressure difference across a valve or shunt can be estimated from the peak velocity (v) as 4v^2. (b) Pulsed Doppler records at a relatively focused position in the heart and if flow is laminar and low velocity there is a sharp outline. This example shows subaortic flow recorded in the left ventricular outflow tract.

Figure 3 Colour Doppler. Colour mapping is an automatic map of mean velocities at each pixel in the sector. In this case, there is a broad jet of mitral regurgitation (arrow) within the left atrium during systole. It has its origin, unusually, through a defect in the base of the anterior mitral leaflet rather than at the orifice. LA, left atrium; LV, left ventricle; RA, right atrium.
New technologies and applications

Echocardiography is advancing at a great rate in both the application of existing modalities, and new technology. Intra-operative transoesophageal echocardiography is used to assess left ventricular function, de-airing of the heart and the competence of valve repair. It is also used for high-risk patients having non-cardiac surgery to detect the development of myocardial ischaemia. Small machines, the size of laptop computers, are now being introduced and are likely to be used on ward rounds, coronary care units and even in general practitioner surgeries or the patient's home.

Coronary disease can be detected by the development of abnormal left ventricular function during ischaemia induced by exercise or intravenous dobutamine. This technique may in the future be refined by the use of intravenous contrast consisting of micro-bubbles that cross the pulmonary circulation and opacify the left heart, before entering the myocardium via the coronary arteries. Such contrast echocardiography is likely to allow the assessment of the coronary microcirculation and provide information similar to that currently obtained using radio-isotopetechniques. Three-dimensional echocardiography remains experimental, but may be useful for planning correction of mitral prolapse, atrial septal defects and malfunctioning prosthetic heart valves.

INDICATIONS FOR ECHOCARDIOGRAPHY

Most studies – about 80% – are requested for the assessment of left ventricular function and to elucidate a murmur (Table 1). There is a basic minimum dataset, but additional views, measurements and manoeuvres may be made depending on the clinical question. A request should therefore include adequate clinical information and a focused reason for the study. For example, it is best to tell the echocardiographer just what findings in acid maltase deficiency can be expected!

Most studies are performed transthoracically with a probe placed parasternally, or over the cardiac apex. However, probes are routinely inserted via the oesophagus and occasionally epicardially (i.e. on the surface of the aorta or heart) during cardiac surgery.

Table 1 Indications for transthoracic echocardiography

| Suspected heart failure
| Symptoms or signs of heart failure, especially with abnormal ECG or chest X-ray
| Unexplained hypotension
| Valve disease including murmur
| Murmur suggesting at least a moderate likelihood of organic disease
| Ejection systolic murmur filling most of systole, or any pansystolic murmur
| Any diastolic murmur
| Abnormal second heart sound
| Wide pulse pressure and displaced apex beat, or enlarged cardiac shadow on chest X-ray
| Evidence of endocarditis
| Routinely soon after valve replacement, or if symptoms or signs suggest dysfunction, or routinely beyond about 7 years if the replacement valve is a xenograft
| Ischaemic stroke, transient ischaemic attack or peripheral embolism
| Clinical evidence of relevant structural heart disease, e.g. mitral stenosis
| Clinical suggestion of endocarditis or myxoma
| Strong suggestion of cardiac emboli (e.g. both peripheral and cerebral events)
| Arrhythmias and syncope
| Clinical suspicion of structural disease, e.g. ventricular tachycardia or atrial fibrillation aged > 60, or abnormal cardiovascular examination
| Atrial fibrillation if the decision to start warfarin will be influenced by left atrial size and left ventricular function
| Family history of a genetic disease, e.g. tuberous sclerosis, hypertrophic cardiomyopathy
| Coronary disease
| Suspicion of postinfarct complication (pansystolic murmur, cardiogenic shock)
| Postinfarction to assess left ventricular function if this will change management (e.g. starting ACE inhibitor)
| Diagnosis of ischaemia (stress echocardiography)
| Diseases of the aorta
| Suspected aortic dissection or rupture
| Widened mediastinum on the chest X-ray
| Serial studies if the ascending aorta is dilated
| Screening
| Family history of genetically transmitted cardiac disease e.g. Marfan's syndrome, hypertrophic cardiomyopathy, dilated cardiomyopathy
| Before and after treatment with potentially cardiotoxic chemotherapy
| Neuromuscular disease with a high frequency of left ventricular dysfunction, e.g. Becker's dystrophy
surgery. Transoesophageal is often seen as better than transthoracic echocardiography because the images are of higher resolution, but in fact the two approaches are complementary. Transthoracic echocardiography is better for imaging the apex of the left ventricle, the anterior aortic root and inferior vena cava and often the upper part of the ascending thoracic aorta. By contrast, the transoesophageal approach (Table 2) is better for the atria, pulmonary veins, posterior aortic root and descending thoracic aorta.

**Left ventricular structure and function**

Echocardiography detects abnormalities of cavity size, wall thickness and motion. Systolic function can be assessed in a variety of ways including cavity volume, ejection fraction, derived rate of pressure change, and cardiac output. Diastolic function can be assessed using Doppler patterns at the mitral tip, and in the pulmonary veins. It is rare to find echocardiographic abnormalities if the resting 12-lead electrocardiogram is completely normal, but even trivial ST or T wave changes may be associated with echocardiographic abnormalities, especially if the likelihood of an abnormality is high, for example in Becker’s dystrophy.

**Murmurs**

Echocardiography is the technique of choice for detecting and quantifying a valve abnormality (Fig. 1) or shunt, and can often determine the aetiology. Quantification of the severity of stenosis is accurate using Doppler echocardiography (Fig. 2a). Regurgitation remains difficult to quantify by any technique, but echocardiography is as accurate as any, using a combination of imaging, continuous wave and colour Doppler (Figs 3 and 4). Echocardiography is not indicated for soft, ejection systolic murmurs with a normal second heart sound, provided the

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**Table 2** Indications for transoesophageal echocardiography (with preparatory transthoracic study)

<table>
<thead>
<tr>
<th>Indication</th>
<th>Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ischaemic stroke, transient ischaemic attack or peripheral embolism</td>
<td></td>
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<tr>
<td>Patients aged &lt; 50 years</td>
<td></td>
</tr>
<tr>
<td>Patients aged &gt; 50 years without evidence of vascular disease in the neck (bruit, ultrasound, etc.) or other obvious cause in whom the findings of echocardiography will change management (e.g. to start warfarin if a patent foramen ovale is found)</td>
<td></td>
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<tr>
<td>Valve disease</td>
<td></td>
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<tr>
<td>Prosthetic mitral valve dysfunction suspected</td>
<td></td>
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<tr>
<td>Suspected endocarditis</td>
<td></td>
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<tr>
<td>To determine feasibility and safety of balloon mitral valvotomy</td>
<td></td>
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<tr>
<td>To determine if some cases of mitral regurgitation are reparable</td>
<td></td>
</tr>
<tr>
<td>Atrial Septal Defect</td>
<td></td>
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<tr>
<td>To determine if percutaneous closure is possible</td>
<td></td>
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<tr>
<td>Aorta</td>
<td></td>
</tr>
<tr>
<td>To diagnose dissection, intramural haematoma or transection</td>
<td></td>
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<tr>
<td>To determine the size of the aorta if the transaortic ‘window’ is poor</td>
<td></td>
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<tr>
<td>Before cardioversion</td>
<td></td>
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<tr>
<td>Previous cardioembolic event,</td>
<td></td>
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<tr>
<td>Anticoagulation contraindicated</td>
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<tr>
<td>Atrial fibrillation of &lt; 48 h duration in the presence of structural heart disease</td>
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</tbody>
</table>

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**Figure 4** Colour M-mode. This technique produces a map of mean velocity and direction at each pixel on the screen displayed against the moving image of the heart. The y-axis represents depth below the transducer and the x-axis represents time. This display greatly simplifies the timing of normal and abnormal flow. With ordinary 2D colour, it may sometimes be difficult to be sure whether an abnormality is systolic or diastolic, especially at high heart rates. Colour M-mode allows transient jets of relatively mild mitral regurgitation to be differentiated from holosystolic jets. In this example, the abnormal flow (in blue) lasts throughout systole. The red part of the map represents forward flow during diastole. The early and atrial filling phases can easily be differentiated.
Figure 5. Patent foramen ovale on transoesophageal imaging. A patent foramen ovale is present in up to 30% of people. Transient ischaemic attacks and ischaemic stroke in young people are probably associated only with large defects. These are usually defined by (a) the passage of more than 20 microbubbles into the left atrium after contrast injection (arrow) or by (b) flow between the atria on colour mapping (arrow). LA, left atrium; RA, right atrium.

Patient is asymptomatic. Such murmurs are caused by mild aortic valve thickening, or are benign systolic flow murmurs.

Stroke/transient ischaemic attack
The main cardiac causes for ischaemic stroke remain clinically obvious – atrial fibrillation, heart failure, mitral stenosis or a prosthetic heart valve in the mitral position. Unless there is an abnormality of the electrocardiogram or on clinical examination, the yield from transthoracic echocardiography is close to zero. Similarly, most abnormalities on transoesophageal echocardiography can be predicted from an abnormal transthoracic study, or directly from the clinical findings, and do not influence subsequent management (e.g. whether thrombus is present or not in a fibrillating left atrium, or in a poorly contracting left ventricle). The main additional benefit of transoesophageal echocardiography is to detect a patent foramen ovale (Fig. 5) although whether this requires treatment with warfarin or mechanical closure is controversial. It is likely that only large patent foramina are causally important and these can mostly be detected using intravenous contrast on transthoracic imaging, provided image quality is good.

However, transoesophageal echocardiography remains an essential tool because it also detects unexpected valvular vegetations, left atrial thrombus (85% in the appendage) despite sinus rhythm, and small myxomas in up to 1% of young patients. ‘Young’ is taken to mean under 45 in the USA but usually under 50 in Europe. Older subjects should only be considered for transoesophageal echocardiography if carotid studies and haematological investigations prove normal; however, the yield is low and the significance of many abnormalities, especially a patent foramen ovale, remains uncertain.

Endocarditis
Echocardiography can provide evidence of endocarditis from the presence of a valvular vegetation (Fig. 6), valve destruction or a local complication (aortic root abscess, leaflet perforation or dehiscence of a prosthetic valve). However, echocardiography cannot differentiate between an infective vegetation and one arising as a result of systemic lupus erythematosus or carcinomatosis. Furthermore, although large vegetations are easy to diagnose (Fig. 6), smaller ones cannot always be reliably differentiated from other causes of valve thickening. Because degenerative changes of the aortic and mitral valves may be found in up to one half of all elderly subjects, serious confusion can arise if these are allowed to suggest endocarditis. For this reason, echocardiography must never be part of a ‘fever screen’ and should only be requested if there is reasonable clinical suspicion of endocarditis.

WHAT DOES ECHOCARDIOGRAPHY INVOLVE FOR THE PATIENT?
Transthoracic echocardiography is performed in a darkened room. The skin of the chest is exposed and electrodes are attached to allow timing of the echocardiographic events within the cardiac cycle. The patient then lies semi-recumbent on the left
side, usually with the left arm behind the neck to enlarge the rib spaces. Ultrasound gel acts as a couplant for the ultrasound to pass between the probe and body. Most images are taken from the left of the sternum and around the left breast, but some in the epigastrium and at the suprasternal notch. An outpatient study takes 20–30 min to perform and 10 min to report.

Transoesophageal echocardiography is semi-invasive, requires adequate clinical facilities and a team, usually consisting of a nurse, clinician and technician, for its safe conduct. There is a small morbidity (brady- or tachy-arrhythmias, oropharyngeal bleeding and haematoma, oesophageal perforation, inhalation pneumonitis) and occasional deaths, usually patients already critically ill or those with unsuspected oesophageal malignancy. The patient must have nothing by mouth for at least 4 h before the investigation. Oxygen is given by nasal cannulae, and the oxygen saturation checked by pulse oximetry. The blood pressure and electrocardiogram must be monitored. An oropharyngeal xylocaine spray induces local anaesthesia and most centres give intravenous sedation, for example with diazemuls or midazolam. The probe is usually inside for about 10–15 min, although the whole study, allowing for a preliminary transthoracic study and recovery, takes about 1 hour.

STRENGTHS AND LIMITATIONS
Echocardiography is safe, widely available, relatively inexpensive and portable. It gives anatomical information, but also a large range of sophisticated physiological data. However, this additional potential can only be realised in expert laboratories, usually with specialist clinical involvement.

In the UK, at least 80% of studies are performed and reported by technicians who range from expert specialist echocardiographers to generalists. If the laboratory is not specialised, and does not have a supervising clinician checking and commenting on studies, a referring clinician should consider asking for a clinical opinion from a cardiologist, not just ‘echocardiography please’ in important or complex cases.

At its best echocardiography is capable of detecting most diseases of the heart and great vessels and is the technique of choice for valve disease. It is not good at tissue characterization, for example to differentiate thickening of the left ventricular wall as a result of muscle hypertrophy from infiltration. For this, magnetic resonance (M.R) or computerized tomography (CT) might be used. Unlike CT or M.R, echocardiography cannot provide reproducibly high resolution three-dimensional views, when these might be essential, as in complex congenital heart disease, or useful, as in chronic stable aortic disease. However, in the presence of acute aortic dissection, echocardiography remains the technique of choice because it can be brought to the intensive care unit or operating room. The standard deviations for estimating left ventricular mass are some 10 times greater for echocardiography than for M.R. Therefore, M.R is probably the technique of choice for research studies of mass regression, while echocardiography remains ideal for screening for left ventricular hypertrophy, for example to help determine which patients with borderline hypertension require treatment.

CONCLUSIONS
Echocardiography is a powerful tool providing information about the structure and function of the heart and great vessels. Most studies are requested for estimating left ventricular function or for elucidating a murmur. Echocardiography cannot be interpreted outside the clinical context and the request form should include background information and a focused reason for the study.

FURTHER READING
Popp RL (1990) Echocardiography, New England Journal of Medicine, 323, 101–9, 165–72. (Old but still useful review article.)

Figure 6 Vegetation. This is a transoesophageal image of a bileaflet mechanical valve in the mitral position. It is fringed by numerous vegetations (arrowed) caused by methicillin resistant staphylococcus aureus. LA, left atrium; LV, left ventricle.