CARDIOLOGY UPDATE

Echocardiography and the general physician

G J Heatlie, M Giles

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Doctors from many medical specialties request echocardiography as part of their assessment of patients with a wide range of pathology. Recent advances in the technology and techniques of echocardiography are discussed. The role of echocardiography in acute medicine is reviewed and its place in general medicine is also discussed.

Since the pioneering work of Edler in the 1950s, echocardiography machines have evolved into highly complex and sophisticated instruments, allowing detailed analysis of cardiac anatomy and function. They have become so widely available that approximately 1 000 000 echo studies are performed each year in the UK, a figure likely to double over the next few years following proposals within the National Service Framework for Coronary Heart Disease and recommendations by the National Institute for Clinical Excellence.

Echocardiography is the first choice for cardiac imaging as:

- (1) It provides detailed information with minimal patient discomfort.
- (2) It uses ultrasound which allows repeat studies as often as is necessary.
- (3) Results are immediately available.
- (4) Unlike alternative technologies, machines are portable, particularly the new generation of hand held units.

The most common reason for requesting an echocardiogram is to assess left ventricular function, accounting for over 50% of studies in the UK and North America.¹ However the indications for an echocardiogram include almost the full spectrum of cardiovascular disease, from ventricular function and valvular disease to arrhythmias and chest pain.

There are a number of competing modalities including magnetic resonance imaging, nuclear scintigraphy, and positron emission tomography. Considerable technical advances in magnetic resonance imaging in cardiology have reduced image acquisition time and increased frame rates to make it a viable alternative to echocardiography. It is also more versatile than echo, giving detailed images of structure and blood flow but at present its use at the bedside or in theatre is impractical due to cost and size.

PRINCIPLES OF ECHOCARDIOGRAPHY

Echo machines are powerful computers linked to an ultrasound generating system. The probe

generates sound waves typically at 2.5 MHz that is 2.5 million times per second. When encountering an object, sound waves are scattered or reflected back towards the probe from the object's interface with adjacent structures; this is repeated in many times per second to build up a moving real time image of the heart.

The Doppler principle is familiar to all school-children as the explanation for the change in tone of the siren of an approaching fire engine. The change in frequency of the returning signal is related to the velocity of the moving object, whether this is a fire engine or red blood cells! Doppler information is normally presented as a graph of blood velocity against time—pulsed wave Doppler measuring velocity at a point and continuous wave Doppler measuring the highest velocity along a scan line.

Thus images and velocities can be acquired by the same probe by measuring different attributes of the same signal (reflected intensity and frequency), providing single dimensional (M-mode), two dimensional, and Doppler images.

The quality of images in modern echo machines is very high with recent technological advances in computing power and probe technology allowing high resolution. The footprint of the probe is very small allowing easy access between ribs, while retaining sufficiently high density of scan lines.

RECENT TECHNOLOGICAL ADVANCES

The most important physical principle to have made an impact on image quality in recent years is *second harmonic imaging*. Interrogation of the received beam at twice the transmitted frequency allows construction of an image from a signal that, although smaller in amplitude, produces much less noise and hence generates a much clearer image. This technique is most valuable when normal imaging produces suboptimal images.

Second harmonic imaging is also useful when agents are injected to provide contrast to improve delineation of cardiac chambers. For example, agitated saline helps in the diagnosis of septal defects. Recent development of transpulmonary echo contrast agents is a leap forward allowing left ventricular cavity opacification (LVO) and augmentation of the Doppler measurement of left heart blood flow. These agents are micro-

See end of article for authors' affiliations

Correspondence to:
Dr Grant Heatlie, Queens
Medical Centre, Derby
Road, Nottingham NG7
2UH, UK; grant.heatlie@
virgin.net

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Abbreviations: COPD, chronic obstructive pulmonary disease; ECG, electrocardiography; LVH, left ventricular hypertrophy; LVO, left ventricular cavity opacification; RVSP, right ventricular systolic pressure; TOE, transoesophageal echocardiography; TTE, transthoracic echocardiography

Figure 1 A tissue Doppler image in the four chamber view. Bottom left is the normal grey scale image and top left is a colour Doppler image where the colour encodes myocardial motion. At a selected point (square) of the myocardium the velocity information is extracted and displayed as a velocity/time graph. The point labelled 1 corresponds to peak systolic contraction velocity, 2 is the peak passive relaxation velocity (passive left ventricular filling), and 3 is the peak myocardial velocity during active left ventricular filling.

bubbles around 5 microns in diameter and contain fluorocarbon gas. They are non-linear oscillators (the energy emitted by the bubbles is at a mixture frequencies) so are suited to second harmonic imaging where the frequency interrogated by the probe is twice the transmitted frequency. In addition to LVO, these agents can be used to observe myocardial perfusion in real time. Single microbubbles are visible and, after the destruction of all the contrast within the image by a powerful ultrasound pulse, the rate of reperfusion in different vascular beds can be calculated. As image quality improves, techniques that are undergoing development will become routine.

More recently the Doppler principle has been applied to myocardial motion so that “speed/time” graphs of muscle velocity can be generated; these provide a novel, quantitative perspective on left ventricular function. It also allows precise measurements of timing of contraction within the ventricles (fig 1). An extension of this method allows analysis of local myocardial deformation (strain/strain rate imaging). It is likely that this will have a variety of applications and may become the method of choice to select patients for biventricular pacing.

OTHER MODALITIES OF ECHOCARDIOGRAPHY

The interposition of lung tissue can restrict “echo windows”, reducing image quality in some patients quite markedly. Transoesophageal echocardiography (TOE) reduces the distance between echo probe and heart so higher frequencies can be used, giving better resolution. Visualisation of structures posterior in the chest such as the left atrium, mitral and aortic valves is excellent, although the left ventricular apex is not particularly well seen. TOE is, of course, an unpleasant, invasive test with a low morbidity due to the risk of haematoma and oesophageal perforation.

TOE should be considered an alternative as complementary to, rather than in competition with, transthoracic echocardiography (TTE).

Stress echocardiography is now widely available and has been validated to demonstrate the presence of myocardial ischaemia or viability.^{2,3} It employs physiological (exercise) or pharmacological (such as dobutamine) stress during echo-

cardiography. Wall motion abnormalities appear before electrocardiography (ECG) changes in the ischaemic heart and these are often more easily seen with contrast enhancement of left ventricular images.

Intravascular ultrasound is sometimes employed during coronary arteriography to improve definition of coronary lesions. Less commonly intracardiac ultrasound is used to guide interventional procedures such as atrial septal defect closures.

Three dimensional echocardiography is now available, giving real time three dimensional views. It will have an important role in congenital heart disease. As the views are similar to what the surgeon is used to seeing in the operating theatre, it is likely that this will be employed widely as a method of pre operative assessment of valvular disease. It may also be employed in interventional cardiology to guide placement of intracardiac catheters.

Figure 2 A transoesophageal image of aortic dissection. The false lumen is marked with an asterisk.

Figure 3 A mass (in this case an infective vegetation) associated with the non-coronary cusp of the aortic valve.

ECHOCARDIOGRAPHY AND THE ACUTE MEDICAL TAKE

Acute myocardial infarction

Echocardiography is not routinely required acutely in uncomplicated myocardial infarction. It does have a role in the investigation of unexplained hypotension and murmurs, providing a rapid and safe bedside assessment of global and regional right and left ventricular and valvular function.

Myocardium may be locally acutely stunned by infarction but remain viable and spontaneously improve, while other conditions such as acidosis can reversibly suppress global myocardial function.

Hypotension may complicate inferior myocardial infarctions. The right ventricle often lies in the same vascular territory as the inferior wall of the left ventricle and so can be damaged simultaneously. The combination of echocardiography and central venous pressure measurements can avoid unnecessary pulmonary artery catheterisation.

Two important complications of acute infarction are ventricular septal defect and acute severe mitral regurgitation, both of which can be diagnosed rapidly and severity established.

Occasionally an unexplained pericardial effusion will be found at the time of a myocardial infarction. An injection of transpulmonary echo contrast can be helpful to diagnose a free wall rupture, which may not otherwise be seen on echo and is important to differentiate from other causes of pericardial effusion.

Figure 4 A large mass in the left atrium (in this case a myxoma) is seen prolapsing through the mitral valve.

Ischaemic heart disease

Stress echocardiography is now available in the UK and is more sensitive and specific than exercise ECG testing, accurately predicting cardiovascular risk after presentation with chest pain. It may also be used to help diagnose the presence of significant coronary artery disease with a similar sensitivity and specificity to other imaging techniques.

The advent of tissue Doppler myocardial imaging in the latest generation of echo machines will improve interobserver reproducibility (a current concern) and measure (two dimensional) myocardial deformation (strain) in real time. Real time myocardial perfusion imaging is likely to move from the research to the clinical arena in the near future.

Aortic dissection

Echocardiography has an important part to play in suspected thoracic aortic dissection (fig 2). The sensitivity and specificity of TOE is similar to that of contrast enhanced computed tomography, although slightly inferior to magnetic resonance imaging.⁴ The investigation of choice usually depends on local expertise as well as factors including when the patient last ate. The relative risks of an invasive procedure (and its effects on haemodynamics) have to be measured against the risk of moving the patient to a non-clinical area in a radiology department.

Transthoracic echo is often seen as an unhelpful investigation for acute aortic dissection due to sensitivity and specificity of around 50% and 60% respectively. While it can never *exclude* dissection, TTE can positively identify some dissections and can give important information about complications such as pericardial effusion and aortic regurgitation.⁴

Pulmonary embolus

Echocardiography can identify specific cardiac abnormalities but should not be relied upon to diagnose pulmonary embolus. For example, TTE often detects a dilated right heart with pulmonary hypertension in acute pulmonary embolus, providing adjunctive information in the clinical context of an acutely hypoxic, hypotensive patient which can be used to guide the need for lytic therapy.

Transoesophageal echo can demonstrate clot in the proximal pulmonary arteries if present but has a low overall sensitivity for the diagnosis of pulmonary embolus.⁵

Table 1 The original Duke's criteria for the diagnosis of endocarditis.⁶ Two major, one major and three minor, or five minor criteria are necessary for the diagnosis of endocarditis

Major Duke's criteria	Minor Duke's criteria
1. Positive blood cultures with a typical organism	1. Predisposing cardiac condition
2. Evidence of endocardial involvement from echocardiography	2. Fever
	3. Vascular phenomena: emboli, mycotic aneurysm, Janeway's lesion
	4. Immunological phenomena: glomerulonephritis, splinter haemorrhages, Roth's spots, Osler's nodes
	5. Positive blood cultures with organism consistent but not typical for endocarditis
	6. Positive echocardiography with findings consistent with but not typical for endocarditis

Arrhythmias

Echocardiography can provide valuable information in the management of atrial fibrillation. Echo variables such as left atrial size and left ventricular function correlate with the success of electrical cardioversion acutely as well as to the likelihood of maintaining sinus rhythm in the longer term.⁶ Echo should normally be requested once the ventricular response to atrial fibrillation is controlled because at high heart rates diastolic relaxation time is brief, making assessment of left ventricular function difficult.

Assessment of left ventricular function by echo in patients with non-syncopal sustained ventricular tachycardia is crucial. Such patients who also have impaired left ventricular function secondary to ischaemic heart disease have a high mortality rate and are best treated with an implantable defibrillator. Patients who have normal (or near normal) left ventricular function have a good prognosis and may be managed medically.

Occult infection and suspected infective endocarditis

Infective endocarditis (fig 3) is often included in the differential diagnosis of sepsis. Confirmation or exclusion of infective endocarditis relies on the established diagnostic Duke's criteria (table 1), in which echocardiography is one of the major criteria.⁷

The sensitivity of TTE for identifying native valve vegetations is 46% and for TOE 93%. Importantly a *negative* TOE has a predictive value of 96%.⁸

In suspected prosthetic valve endocarditis, TTE is less helpful as the prosthetic valve produces acoustic shadows which obscure important structures. In this situation, TOE is mandatory, providing a more complete assessment and clearer views of both prosthetic valve and supporting structures. In particular, TOE is superior at visualising the aortic root for complications such as aortic root abscess.

Indications for TOE include a normal TTE despite the presence of one major or two minor Duke's criteria, the presence of prosthetic valves and all cases of endocarditis confirmed with TTE.

Monitoring of valvular disease

This forms a large part of the echo workload. Most of this is done from cardiology clinics, with the aim of determining the optimum timing of intervention. This is a complex issue and will not be covered in detail here.

ECHOCARDIOGRAPHY AND THE RESPIRATORY PHYSICIAN

Pulmonary arterial hypertension develops in the presence of chronic lung disease, causing right ventricular pressure overload. The right ventricle compensates by muscular hypertrophy, conformational changes, and developing higher filling pressures. These changes are described as *cor pulmonale*.

It is possible to monitor pulmonary pressures as disease states progress or during therapeutic interventions by studying pulmonary and tricuspid regurgitation which can be observed in most patients. Right ventricular systolic pressure (RVSP) can be estimated relatively easily from the peak regurgitant velocity of the tricuspid valve and adding an estimate of right atrial pressure, which can be obtained either clinically or by studying the inferior vena cava. In the absence of pulmonary stenosis, RVSP equals pulmonary systolic pressure. End diastolic and mean pulmonary artery pressures can similarly be estimated from pulmonary regurgitant profiles. Other signs of pulmonary hypertension such as right ventricular enlargement and hypertrophy, interventricular septal flattening, and right ventricular impairment may be present.

Table 2 Other diseases that affect cardiac structure

Diabetes	Impairment of systolic and diastolic cardiac function
Chronic hypothyroidism	Impairment of systolic and diastolic cardiac function, pericardial effusion
Acromegaly	Left ventricular hypertrophy
Hyperparathyroidism	Valvular and myocardial calcification
Chronic renal failure	Valvular calcification, left ventricular hypertrophy and reduced function, pericardial thickening and effusion

Right ventricular ejection fraction provides important prognostic information in a wide range of patients, particularly those with heart failure and low left ventricular ejection fractions. Unfortunately, due to the complexity of right ventricular anatomy, it has not proved possible to accurately quantify right ventricular function using echocardiography, although the advent of three dimensional echo should eventually achieve this. At present, echocardiography relies on a simple visual assessment or on semiquantitative methods. Of these, the easiest is the measurement of the motion of the tricuspid valve annulus towards the apex during systole by M-mode or tissue Doppler, which correlates well with right ventricular ejection fraction.⁹ The index of myocardial performance is another semiquantitative assessment, which has shown promise in the assessment of patients with pulmonary hypertension. It is obtained from Doppler derived systolic and diastolic time intervals and is easy to perform, reproducible, and not significantly affected by variables such as heart rate, ventricular size, or pressures.¹⁰

Dyspnoea is a universal symptom in respiratory medicine clinics and very common in cardiac clinics. Transthoracic echo can help to differentiate "cardiac" breathlessness due to impaired left ventricular function or valvular disease from "respiratory" breathlessness.

Patients with chronic obstructive pulmonary disease (COPD) can be difficult echo subjects due to hyperinflated lungs attenuating the ultrasound beam. The presence of pulmonary hypertension in COPD is a poor prognostic indicator independent of other factors.

Cor pulmonale also occurs with interstitial lung disease and tends to present late in the course of the disease. The pulmonary artery pressure mirrors the degree of hypoxaemia. The exception is CREST syndrome where pulmonary hypertension is a major feature and presents early, even in the absence of interstitial lung disease.

Echo and the neurologist

The role of echocardiography in the diagnosis and management of patients presenting with neurological disorders is controversial. Most investigators have demonstrated that some clinical evidence of heart disease must be evident for echocardiography to be diagnostically useful. The main exception is patients over 45 years of age where a patent foramen ovale and atrial septal aneurysms are two or three times more common than in older patients.¹¹ However, echocardiography is a widely used tool in the diagnosis, risk stratification, and management of syncope and embolic stroke patients.

Echocardiography is used in syncope primarily to confirm or exclude the presence of obstructive cardiac lesions such as aortic stenosis or hypertrophic cardiomyopathy. Syncope is more likely to be due to a malignant tachyarrhythmia if left ventricular systolic function is impaired.

Up to 40% of ischaemic strokes are embolic in nature and the heart is usually the embolic source. TTE can be used to find and assess most sources of embolus ranging from left

atrial myxoma (fig 4) to left ventricular mural thrombus. Other potential sources of embolus such as patent foramen ovale and left atrial appendage thrombus usually require TOE for diagnosis.

ECHO AND THE GENERAL PHYSICIAN

Pericardial effusion

Inflammatory, neoplastic, endocrine, traumatic, and other disease processes lead to an accumulation of fluid in the pericardial space. Echocardiography allows the definition of size and localisation of any pericardial collection. As fluid accumulates the normally negative pressure in the pericardial space increases and becomes positive, affecting the haemodynamics of the heart. Its effect is more marked in the right heart due to lower pressure. The clinical and echocardiographic signs of tamponade then develop, including right atrial and right ventricular wall diastolic collapse and marked respiratory swings in the left heart blood flow, reflecting reduced filling of the right ventricle. Echo can be used to guide therapeutic pericardiocentesis.

Hypertension

Clinical and epidemiological studies have convincingly demonstrated the independent prognostic value of echocardiographically determined left ventricular hypertrophy (LVH) in hypertensive patients. Long term studies report an incidence of any cardiovascular event of 30% in the presence of concentric LVH, 25% in those with eccentric LVH, 15% in those with concentric remodelling, and only 9% in those with normal left ventricular mass and morphology.¹²

Echocardiographic screening of hypertensive patients who have "borderline" readings may prompt treatment to be prescribed if LVH is present, as this represents end organ damage.

Autoimmune disorders

The connective tissue disorders are associated with a number of cardiac abnormalities. These may affect cardiac valves (granulomas, regurgitation, Liebmann Sacks vegetations, leaflet fibrosis), myocardium (ischaemia, myopathy, fibrosis), or pericardium (pericarditis with or without effusion), together with indirect effects such as the development of pulmonary hypertension. All of these can be detected using echocardiography.

Other diseases

A variety of renal, endocrine, and nutritional disorders may affect cardiac structure and function as illustrated in table 2.

Echocardiography can thus provide a wide range of information in a variety of non-cardiac diseases.

CONCLUSIONS

Echocardiography is an important tool to assist the general physician in the diagnosis and management of medical emergencies and in the investigation of cardiac manifestations of many diseases. It is readily available and recent technological developments mean that the image quality is high for most patients. Its cost, portability, and flexibility will ensure its position as the principle cardiac imaging modality for the foreseeable future.

Authors' affiliations

G J Heatlie, Queens Medical Centre, Nottingham, UK

M Giles, Department of Cardiology, Nottingham City Hospital, UK

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