Chapter 1

What is echo?

1.1 Basic notions

Echocardiography (echo) – the use of ultrasound to examine the heart – is a safe, powerful, non-invasive and painless technique.

Echo is easy to understand as many features are based upon simple physical and physiological facts. It is a practical procedure requiring skill and is very operator dependent – the quality of the echo study and the information derived from it are influenced by who carries out the examination!

This chapter deals with:

- Ultrasound production and detection
- The echo techniques in common clinical use
- The normal echo
- Who should have an echo.

Ultrasound production and detection

Sound is a disturbance propagating in a material – air, water, body tissue or a solid substance. Each sound is characterized by its frequency and its intensity. Frequency is measured in hertz (Hz), i.e. in oscillations per second, and its multiples (kiloHz, kHz, 10^3 Hz and megaHz, MHz, 10^6 Hz). Sound of frequency higher than 20 kHz cannot be perceived by the human ear and is called ultrasound. Echo uses ultrasound of frequencies ranging from about 1.5 MHz to about 7.5 MHz. The nature of the material in which the sound propagates determines its velocity. In the heart, the velocity is 1540 m/s. The speed of sound in air is 330 m/s.

The wavelength of sound equals the ratio of velocity to frequency. In heart tissue, ultrasound with a frequency of 5 MHz has a wavelength of about 0.3 mm. The shorter the wavelength, the higher is resolution. As a rough estimate, the smallest size that can be resolved by a sound is equal to its wavelength. On the other hand, the smaller the wavelength of the sound, the less its penetration power. So a compromise has to be struck between resolution and penetration. A higher frequency of ultrasound can be used in children since less depth of penetration is needed.

Ultrasound results from the property of certain crystals to transform electrical oscillations (varying voltages) into mechanical oscillations (sound). This is called the piezoelectric effect (Fig. 1.1). The same crystals can also act as ultrasound receivers since they can effect the transformation in the opposite direction (mechanical to electrical).

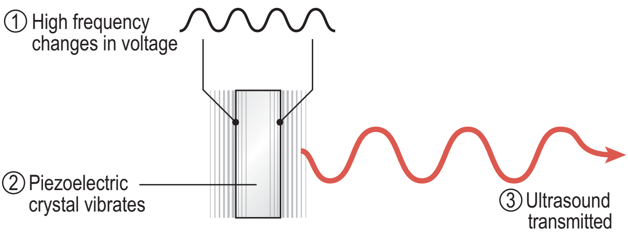


Fig. 1.1 Piezoelectric effect.

The repetition rate is 1000/second. Each transmitting and receiving period lasts for 1 msec. Transmission accounts for 1 microsec of this time. The remaining time is spent in 'receiving' mode.

At the core of any echo machine is this piezoelectric crystal transducer. When varying voltages are applied to the crystal, it vibrates and transmits ultrasound. When the crystal is in receiving mode, if it is struck by ultrasound waves, it is distorted. This generates an electrical signal which is analysed by the echo machine. The crystal can receive as long as it is not transmitting at that time. This fixes the function of the crystal – it emits a pulse and then listens for a reflection.

When ultrasound propagates in a uniform medium, it maintains its initial direction and is progressively absorbed or scattered. If it meets a discontinuity such as the interface of 2 parts of the medium having different densities, some of the ultrasound is reflected back. Ultrasound meets many tissue interfaces and echo reflections occur from different depths. Some interfaces or tissues are more echo-reflective than others (e.g. bone or calcium are more reflective than blood) and these appear as echo-bright reflections.

Two quantities are measured in an echo:

1. The time delay between transmission of the pulse and reception of the reflected echo
2. The intensity of the reflected signal, indicating the echo-reflectivity of that tissue or tissue–tissue interface.

The signals that return to the transducer therefore give evidence of depth and intensity of reflection. These are transformed electronically into greyscale images on a TV screen or printed on paper – high echo reflection is white, less reflection is grey and no reflection is black.

1.2 Viewing the heart

Echo studies are carried out using specialized ultrasound machines. Ultrasound of different frequencies (in adults usually 2–4 MHz) is transmitted from a transducer (probe) which is placed on the subject's anterior chest wall. This is transthoracic echo (TTE). The transducer usually has a line or dot to help rotate it into the correct position to give different echo views. The subject usually lies in the left lateral position and ultrasound jelly is placed on the transducer to ensure good images. Continuous electrocardiograph (ECG) recording is performed and phonocardiography may be used to time cardiac events. An echo examination usually takes 15–20 min.

Echo 'windows' and views (Fig. 1.2)

There are a number of standard positions on the chest wall for the transducer where there are 'echo windows' that allow good penetration by ultrasound without too much masking and absorption by lung or ribs.

A number of sections of the heart are examined by echo from these transducer positions, which are used for 2 main reasons:

1. There is a limitation determined by the anatomy of the heart and its surrounding structures
2. To produce standardized images that can be compared between different studies.

Useful echo information can be obtained in most subjects, but the study can be technically difficult in:

- Very obese subjects

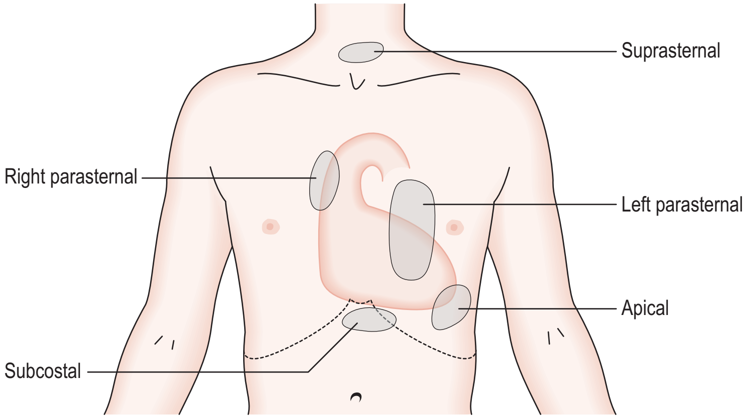


Fig. 1.2 The main echo 'windows'.

- Those with chest wall deformities
- Those with chronic lung disease (e.g. chronic airflow limitation with hyperinflated lungs or pulmonary fibrosis).

Rarely, an echo study is impossible.

A number of 'echo views' are obtained in most studies. 'Axis' refers to the plane in which the ultrasound beam travels through the heart.

Left parasternal window (2nd–4th intercostal space, left sternal edge)

1. **Long-axis view** (Figs 1.3, 1.4). Most examinations begin with this view. The transducer is used to obtain images of the heart in long axis, with slices from the base of the heart to the apex. The marker dot on the transducer points to the right shoulder.
2. **Short-axis views** (Figs 1.5, 1.6). Without moving the transducer from its location on the chest wall and by rotating the transducer through 90° so the marker dot is pointing towards the left shoulder, the heart is cut in transverse (short-axis) sections. By changing the angulation on the chest wall, it is possible to obtain any number of short-axis views, but the standard 4 are at the level of the aortic valve (AV), mitral valve (MV), left ventricular papillary muscles and left ventricular apex (Figs 1.5, 1.6).

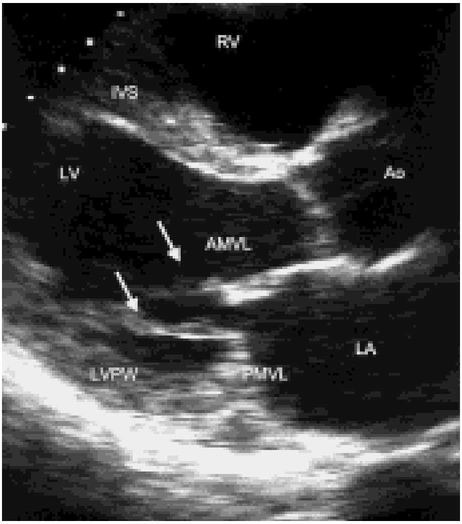


Fig. 1.3 Parasternal long-axis view. Arrows show chordae.

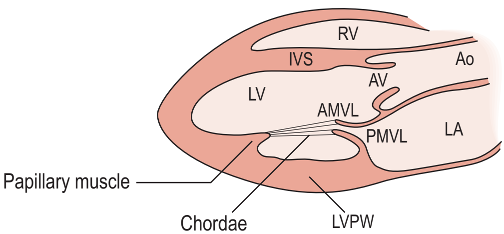


Fig. 1.4 Parasternal long-axis view.

Apical window (cardiac apex)

1. **4-chamber view** (Fig. 1.7a, 1.8). The transducer is placed at the cardiac apex with the marker dot pointing down towards the left shoulder. This gives the typical 'heart-shaped' 4-chamber view (Fig. 1.7a).

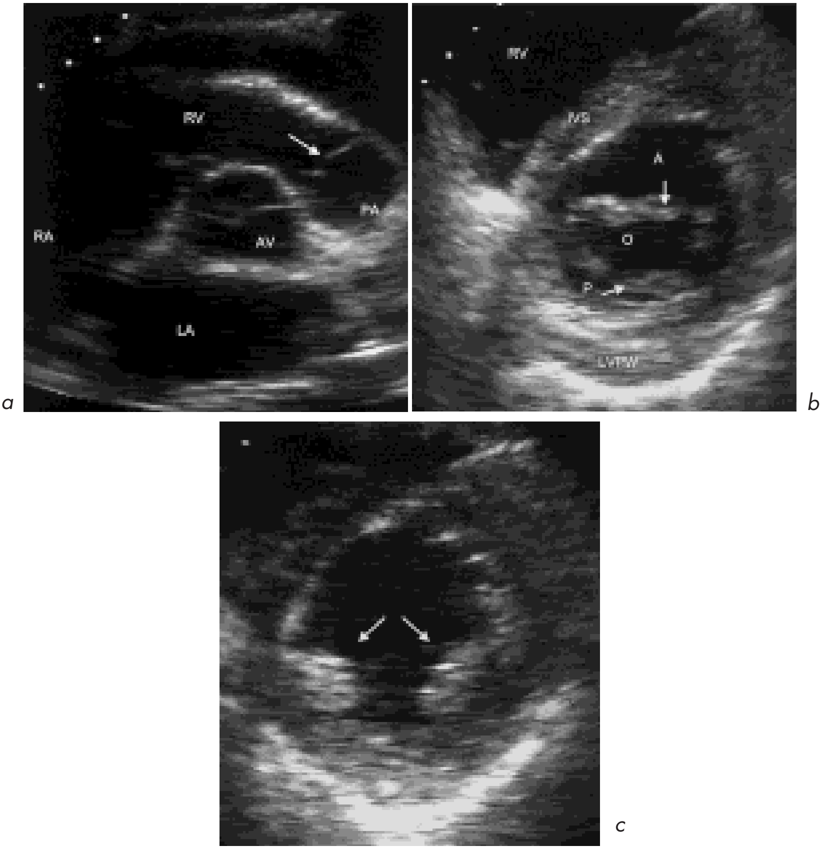


Fig. 1.5 Parasternal short-axis views: (a) Aortic valve level. The pulmonary valve is shown (arrow). (b) Mitral valve level. The anterior (A) and posterior (P) leaflets are shown. Mitral orifice (O). (c) Papillary muscles (arrows) level.

2. **5-chamber (including aortic outflow)** (Fig. 1.7b, 1.8). By altering the angulation of the transducer so the ultrasound beam is angled more anteriorly towards the chest wall, a '5-chamber' view is obtained. The 5th 'chamber' is not a chamber at all but is the AV and ascending aorta. This is useful in assessing aortic stenosis (AS) and aortic regurgitation (AR).

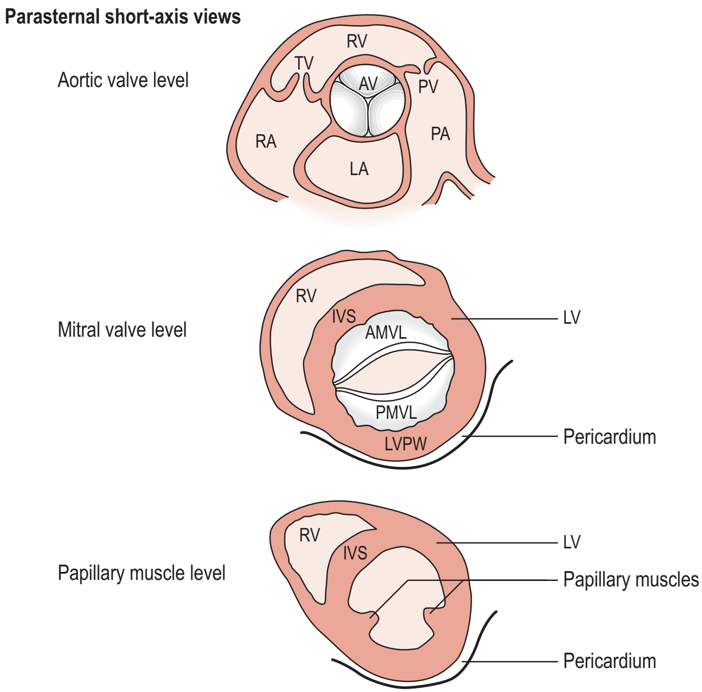


Fig. 1.6 Parasternal short-axis views.

3. **Long-axis and 2-chamber views** (Fig. 1.7c)**.** By rotating the transducer on the cardiac apex it is possible to obtain apical long-axis and 2-chamber views which show different segments of the left ventricle (LV) (Fig. 1.8).

Subcostal window (under the xiphisternum) (Fig. 1.9):

Similar views to apical views, but rotated by 90°. Useful in lung disease, for imaging the interatrial septum, inferior vena cava (IVC) and abdominal aorta.

Further windows may be used:

Suprasternal window (for imaging the aorta in coarctation)

Right parasternal window (in AS and to examine the ascending aorta)

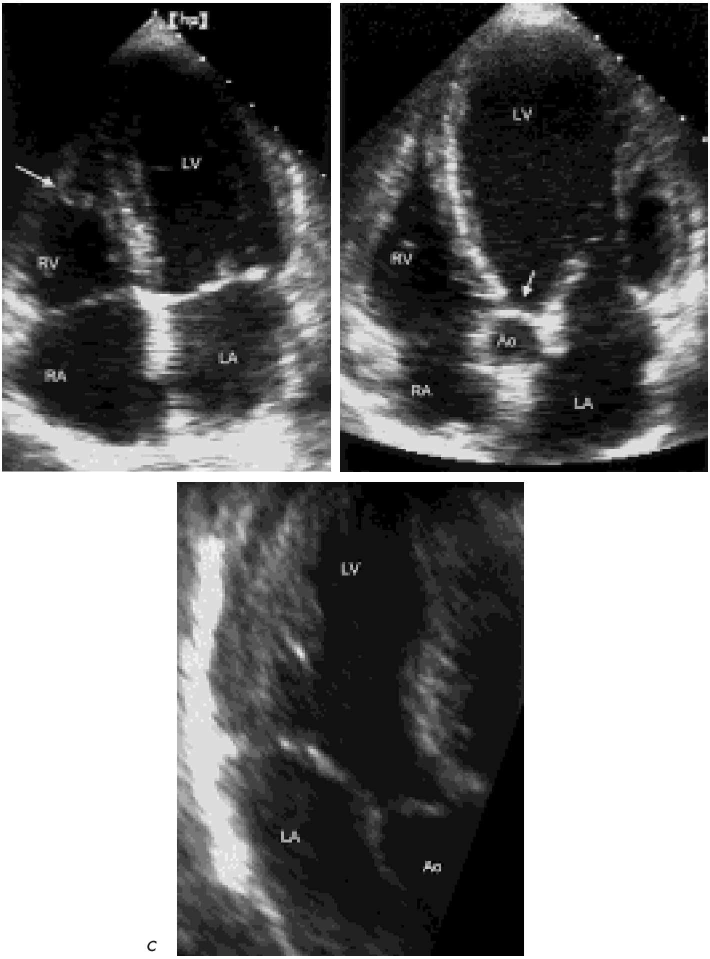


Fig. 1.7 Apical views: (a) Apical 4-chamber view. A moderator band is shown (arrow). This is a normal neuromuscular bundle carrying right bundle branch fibres. (b) Apical 5-chamber view. The aortic valve is shown (arrow). (c) Apical long-axis view.

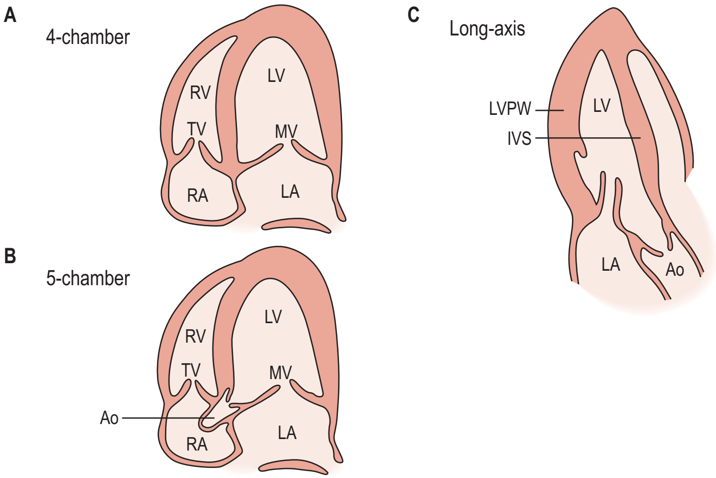


Fig. 1.8 Apical views.

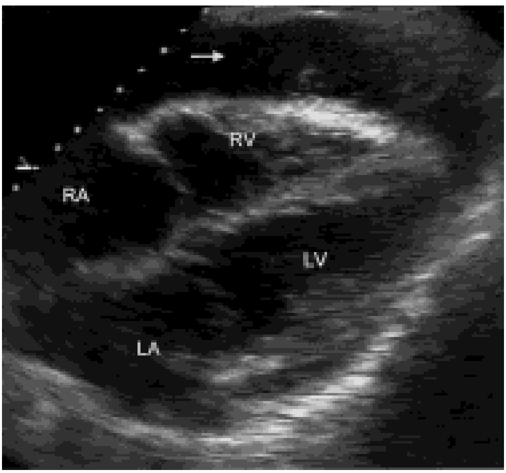


Fig. 1.9 Subcostal 4-chamber view. A pericardial effusion is seen (arrow).

1.3 Echo techniques

Three echo methods are in common clinical usage:

- Two-dimensional (2-D) or 'cross-sectional'
- Motion or M-mode
- Doppler – continuous wave, pulsed wave and colour flow

2-D echo gives a snapshot in time of a cross-section of tissue. If these sections are produced in quick succession and displayed on a TV screen, they can show 'real-time imaging' of the heart chambers, valves and blood vessels.

To create a 2-D image, the ultrasound beam must be swept across the area of interest. The transducer rotates the beam it produces through a certain angle, either mechanically or electronically (Fig. 1.10). In the first case, the transducer is rotated so that its beam scans the target. In the second case, several crystals are mounted together and are excited by voltages in sequence. Each crystal emits waves. The result is a summation wave which moves in a direction determined

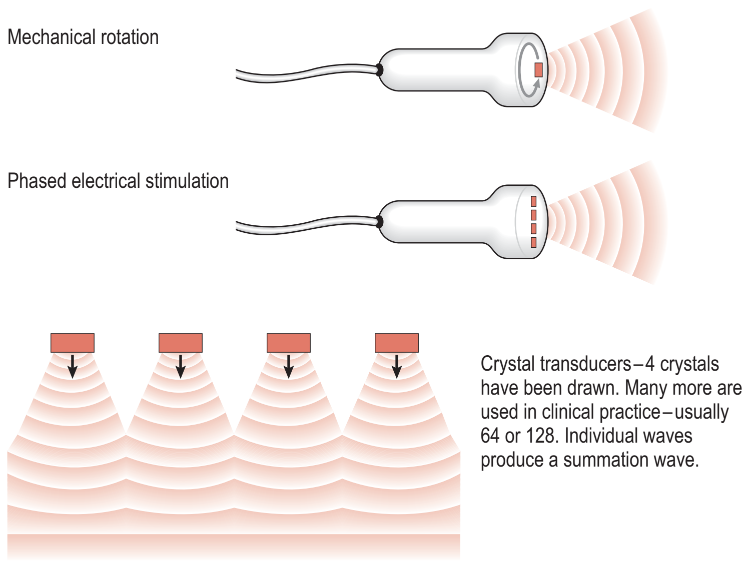


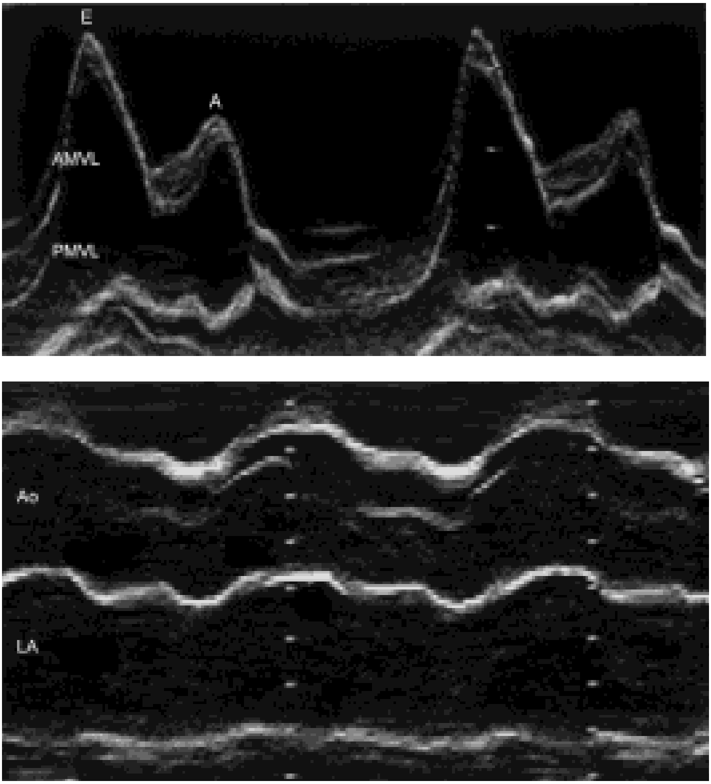
Fig. 1.10 Mechanical and electronic transducers.

by the 'phased stimulation' of the crystals. The reflected ultrasound generates an electrical signal in the crystal, which is used to produce a dot on the TV screen. Ultrasound is transmitted along scan lines (usually about 120 lines) over an arc of approximately 90° at least 20–30 times per second and in some newer systems up to 120 times per second. Reflected ultrasound signals are combined on the TV screen to build up a moving image. Frozen images can be printed out on paper or photographic film.

Motion or M-mode echo (Fig. 1.11) is produced by the transmission and reception of an ultrasound signal along only one line, giving high sensitivity (greater than 2-D echo) for recording moving structures. It produces a graph of depth and strength of reflection with time. Changes in movement (e.g. valve opening and closing or ventricular wall movement) can be displayed. The ultrasound signal should be aligned perpendicularly to the structure being examined. Measurement of the size and thickness of cardiac chambers can be made either manually on paper printouts or on the TV screen using computer software.

Doppler echo uses the reflection of ultrasound by moving red blood cells. The Doppler principle is used to derive velocity information (Ch. 3). The reflected ultrasound has a frequency shift relative to the transmitted ultrasound, determined by the velocity and direction of blood flow. This gives haemodynamic information regarding the heart and blood vessels. It can be used to measure the severity of valvular narrowing (stenosis), to detect valvular leakage (regurgitation) and can show intracardiac shunts such as ventricular septal defects (VSDs) and atrial septal defects (ASDs) (Ch. 6). The 3 commonly used Doppler echo techniques are:

1. **Continuous wave Doppler.** Two crystals are used – one transmitting continuously and one receiving continuously. This technique is useful for measuring high velocities but its ability to localize precisely a flow signal is limited since the signal can originate at any point along the length or width of the ultrasound beam (Fig. 1.12).
2. **Pulsed wave Doppler** (Fig. 1.13). This allows a flow disturbance to be localized or blood velocity from a small region to be measured. A single crystal is used to transmit an ultrasound signal and then to receive after a pre-set time delay. Reflected signals are only recorded from a depth corresponding to half the product of the time delay and the speed of sound in tissues (1540 m/s). By combining this technique with 2-D imaging, a small 'sample volume' can be



a

b

Fig. 1.11 M-mode patterns. (a) Mitral valve and (b) aortic root and left atrium.

identified on the screen showing the region where velocities are being measured. The operator can move the sample volume. Because the time delay limits the rate at which sampling can occur, there is a limit to the maximum velocity that can be accurately detected, before a phenomenon known as ‘aliasing’ occurs, usually at velocities in excess of 2 m/s.

Continuous wave and pulsed wave Doppler allow a graphical representation of velocity against time and are also referred to as ‘spectral Doppler’.

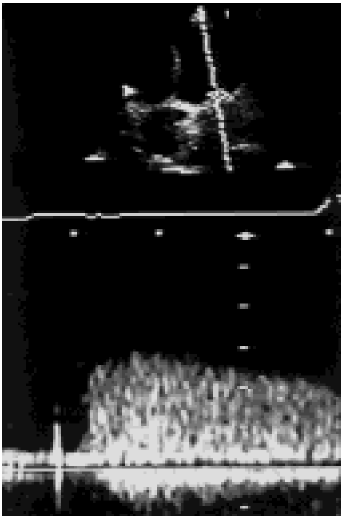


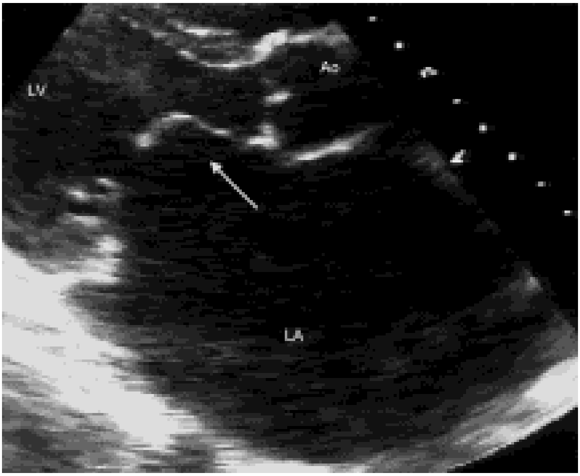
Fig. 1.12

Fig. 1.13

Fig. 1.12 Continuous wave Doppler of severe mitral stenosis. Mean gradient 20 mmHg.

Fig. 1.13 Pulsed wave Doppler. Normal mitral flow pattern.

3. **Colour flow mapping.** This is an automated 2-D version of pulsed wave Doppler. It calculates blood velocity and direction at multiple points along a number of scan lines superimposed on a 2-D echo image. The velocities and directions of blood flow are colour-encoded. Velocities away from the transducer are in blue, those towards it in red. This is known as the BART convention (Blue Away, Red Towards). Higher velocities are shown in progressively lighter shades of colour. Above a threshold velocity, 'colour reversal' occurs (explained again by the phenomenon of aliasing). Areas of high turbulence or regions of high flow acceleration are often indicated in green (Fig. 1.14).



a

b

Fig. 1.14 Rheumatic mitral regurgitation and stenosis. The left atrium is very enlarged. (a) The anterior leaflet shows 'elbowing' (arrow) on parasternal long-axis view. (b) A jet of mitral regurgitation is seen (arrow) on colour flow mapping in the apical 4-chamber view.

Summary of echo modalities and their main uses

2-D echo	• anatomy • ventricular and valvular movement • positioning for M-mode and Doppler echo
M-mode echo	• measurement of dimensions • timing cardiac events
Pulsed wave Doppler	• normal valve flow patterns • LV diastolic function • stroke volume and cardiac output
Continuous wave Doppler	• severity of valvular stenosis • severity of valvular regurgitation • velocity of flow in shunts
Colour flow mapping	• assessment of regurgitation and shunts.

1.4 The normal echo

Echo provides a great deal of anatomical and haemodynamic information:

- Heart chamber size
- Chamber function (systolic and diastolic)
- Valvular motion and function
- Intracardiac and extracardiac masses and fluid collections
- Direction of blood flow and haemodynamic information (e.g. valvular stenosis and pressure gradients) by Doppler echo.

'Normal echo ranges'

It is important to remember that these 'normal ranges' vary with a number of factors. The frequently quoted values of, e.g. left atrial diameter or left ventricular cavity internal dimensions do not take this into account. Important factors which influence cardiac dimensions measured by echo are:

- Height
- Sex
- Age
- Physical training (athletes).

In general, values are higher in taller individuals, males and athletes.

Some correction for these factors can be made, e.g. in very tall individuals, by indexing the measurement to body surface area (BSA):

$$\text{BSA (m}^2\text{)} = \sqrt{\frac{\text{height (cm)} \times \text{weight (kg)}}{3600}}$$

Bearing these points in mind, it is useful to have an indication of some *approximate* echo-derived **'Normal values' for an adult:**

Left ventricle			
Internal diameter	end-systolic		2.0–4.0 cm
	end-diastolic		3.5–5.6 cm
Wall thickness	(diastolic)	septum	0.6–1.2 cm
		posterior wall	0.6–1.2 cm
	(systolic)	septum	0.9–1.8 cm
		posterior wall	0.9–1.8 cm
Fractional shortening			30–45%
Ejection fraction			50–85%
Left atrium (LA)			
Diameter			2.0–4.0 cm
Aortic root			
Diameter			2.0–4.0 cm
Right ventricle (RV)			
Diameter (systolic – diastolic)			0.7 – 2.3 cm

Some other findings on echo may be normal:

1. Mild tricuspid and mitral regurgitation (MR) are found in many normal hearts
2. Some degree of thickening of AV leaflets with ageing is normal without significant aortic stenosis
3. Mitral annulus (ring) calcification is sometimes seen in older subjects. It is often of no consequence but may be misdiagnosed as a stenosed valve, a vegetation (inflammatory mass), thrombus (clot) or myxoma (cardiac tumour). It is important to examine the leaflets carefully. It may be associated with MR (Fig. 1.15) .

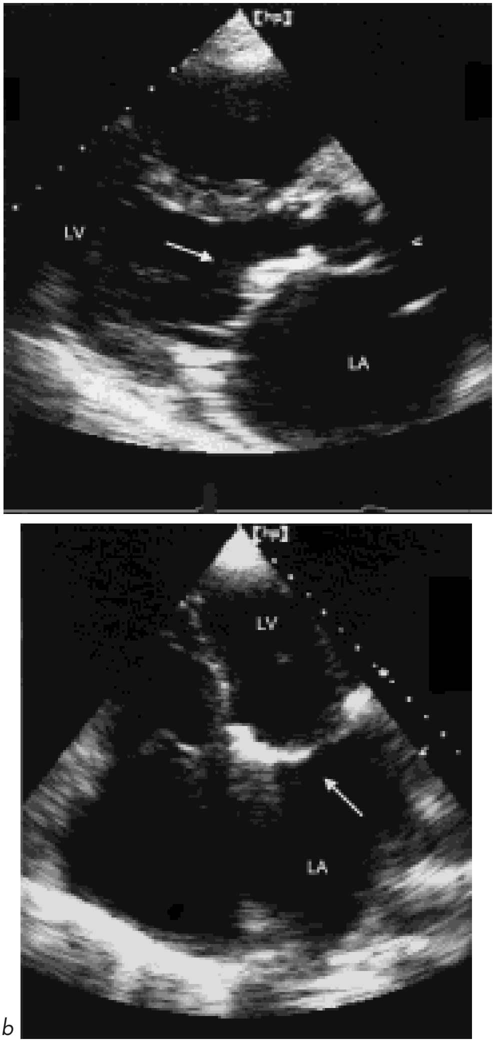


Fig. 1.15 Calcification of mitral annulus (arrow). This was asymptomatic, with no mitral stenosis or regurgitation. (a) Parasternal long-axis view, (b) Apical 4-chamber view.

4. An 'upper septal bulge' (Fig. 1.16) is common, particularly in elderly women, and should not be misdiagnosed as hypertrophic cardiomyopathy (HCM). It is due to septal hypertrophy and fibrosis and only rarely causes significant LV outflow tract obstruction (LVOTO).

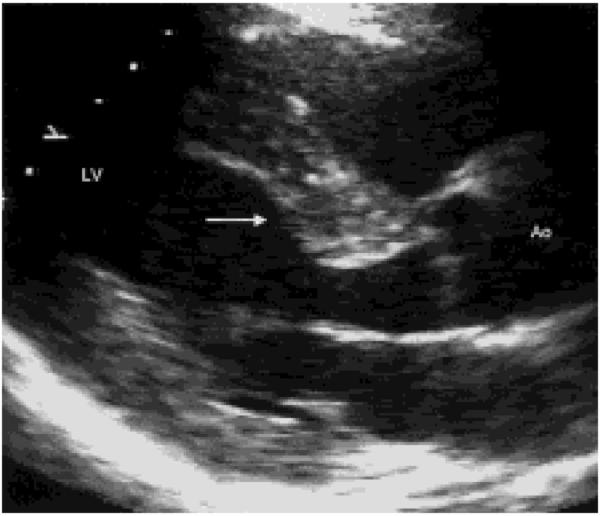


Fig. 1.16 Upper septal bulge (arrow). Parasternal long-axis view.

1.5 Who should have an echo?

In order to obtain the most useful information, it is essential to provide:

- Adequate clinical information
- The reason an echo is being requested
- The specific question being asked.

Examples: ’60-year-old man with breathlessness and previous anterior myocardial infarction, awaiting general anaesthesia for elective hip replacement surgery – please assess LV systolic function’, or, ‘70 year-old woman with aortic ejection systolic murmur – please assess severity of aortic stenosis.’

The following list of indications is not exhaustive and others are found in the relevant sections of the book. The list gives situations in which an echo may influence the clinical management of a patient:

- Assessment of valve function, e.g. systolic or diastolic murmur
- Assessment of left ventricular function – systolic, diastolic and regional wall motion, e.g. suspected heart failure in a subject with breathlessness or oedema, or pre-operative assessment
- Suspected endocarditis
- Suspected myocarditis
- Cardiac tamponade
- Pericardial disease (e.g. pericarditis) or pericardial effusion, especially if clinical evidence of tamponade
- Complications of myocardial infarction (MI), e.g. VSD, MR, effusion
- Suspicion of intracardiac masses – tumour, thrombus
- Cardiac chamber size, e.g. LA in atrial fibrillation (AF), cardiomegaly on chest X-ray
- Assessment of artificial (prosthetic) valve function
- Arrhythmias, e.g. AF, ventricular tachycardia (VT)
- Assessment of RV and right heart
- Estimation of intracardiac and vascular pressures, e.g. pulmonary artery systolic pressure (PASP) in lung disease and suspected pulmonary hypertension (PHT)
- Stroke and transient ischaemic attack (TIA) – ‘cardiac source of embolism?’
- Exclusion of left ventricular hypertrophy (LVH) in hypertension
- Assessment of congenital heart disease.

1.6 Murmurs

A murmur is a sound caused by turbulent blood flow. It may be caused by:

- High velocity or volume across a normal valve
- Forward flow across a diseased valve
- Leakage across a valve
- Flow through a shunt (an abnormal communication between chambers or vessels)
- Flow across a narrowed blood vessel .

Echo helps to diagnose the underlying cause of a murmur and the severity of the haemodynamic effect, and to plan treatment.

1. Possible causes of a systolic murmur

- Benign flow murmur – features suggesting this are short, ejection, mid-systolic, soft or moderate in loudness, normal second heart sound, may be louder on inspiration or on lying flat
- Aortic – 'sclerosis' or stenosis
- HCM
- Mitral – regurgitation, prolapse
- Pulmonary – stenosis
- Tricuspid – regurgitation (rarely heard – diagnosis made by seeing systolic waves in jugular venous pressure (JVP))
- Shunts – intracardiac or extracardiac – congenital, e.g. ASD (high flow across pulmonary valve (PV)), VSD, patent ductus arteriosus (PDA) or acquired (e.g. post-MI VSD)
- Coarctation of the aorta.

2. Conditions associated with a benign systolic murmur

(no underlying cardiac disease) – common in childhood and pregnancy

- Pulmonary flow – common, especially in young children (30%)
- Venous hum – continuous, reduced by neck vein compression, turning head laterally, bending elbows or lying down. Loudest in neck and around clavicles
- Mammary souffle – particularly in pregnancy

- High-flow states – pregnancy, anaemia, fever, anxiety, thyrotoxicosis* (*although there may be associated cardiac disease).

3. Possible causes of a diastolic murmur

Abnormal – except venous hum or mammary souffle

- Aortic – regurgitation
- Mitral – stenosis
- Pulmonary – regurgitation
- Tricuspid – stenosis (rare)
- Congenital shunts – e.g. PDA.

4. Who with a murmur should have an echo?

Features suggesting a murmur is pathological/organic

An echo should be requested for anyone whose murmur is not clearly clinically benign (e.g. pulmonary flow, venous hum, mammary souffle) especially if there are any features of a pathological murmur:

- Symptoms – chest pain, breathlessness, oedema, syncope, dizziness, palpitations
- Cyanosis
- Thrill (palpable murmur)
- Diastolic murmur*
- Pansystolic*
- Very loud murmur (but remember – the *loudness* of a murmur often bears no relation to the *severity* of the valve lesion)
- Added/abnormal heart sounds – abnormal S_2, ejection clicks, opening snaps, S_4 (not S_3 which can be normal, particularly if age < 30 years)
- Physical signs of heart failure
- Wide pulse pressure and displaced apex
- Suspected endocarditis
- Suspected aortic dissection
- Cardiomegaly (e.g. on chest X-ray)
- Associated ECG abnormalities, e.g. LVH
  (*exceptions are venous hum or mammary souffle as above).