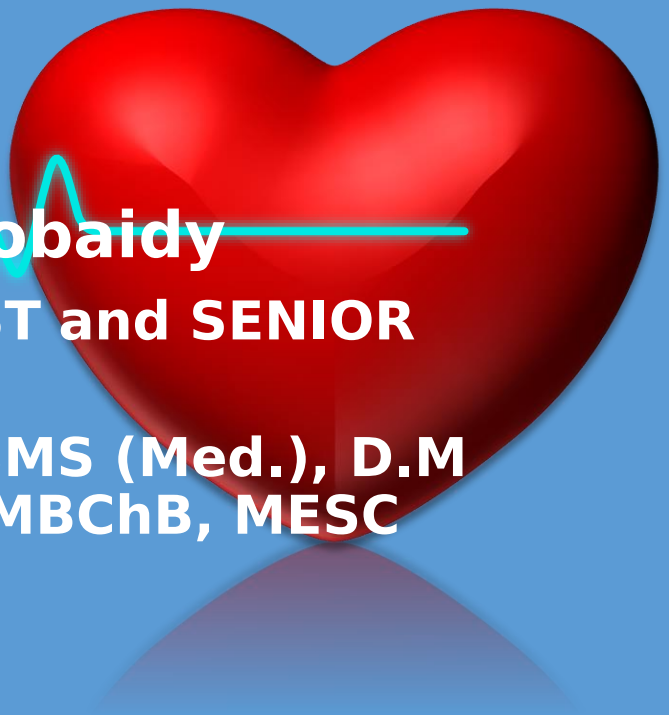
Investigation of cardiovascular disease



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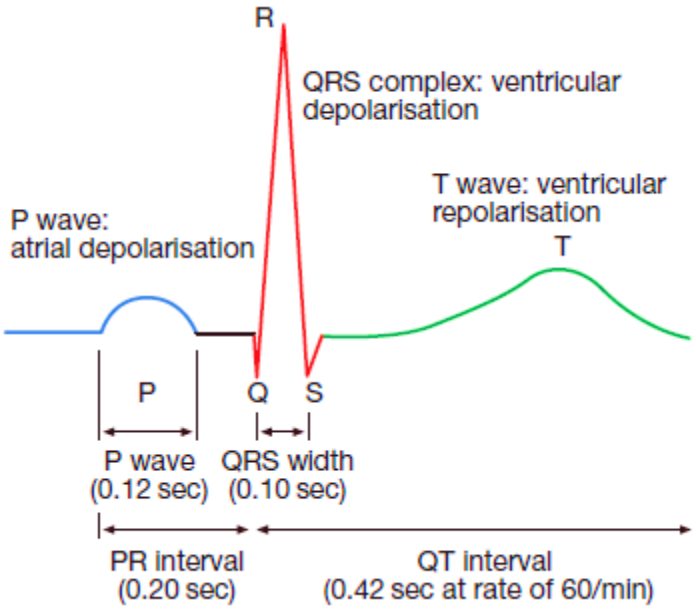
Investigation of cardiovascular disease

Electrocardiogram

The electrocardiogram (ECG) is used to assess cardiac rhythm and conduction, and is the main test used in the diagnosis of myocardial ischaemia and infarction.

The physiological basis of an ECG recording is the fact that electrical depolarisation of myocardial tissue produces a small dipole current, which can be detected by electrode pairs on the body surface.

These signals are amplified and either printed or displayed on a monitor. During sinus rhythm, the SA node triggers **atrial depolarisation, producing a P wave**. Depolarisation proceeds slowly through the AV node, which is too small to produce a depolarisation wave detectable from the body surface. The bundle of His, bundle branches and Purkinje system are then activated, **initiating ventricular myocardial depolarisation, which produces the QRS complex.** The muscle mass of the ventricles is much larger than that of the atria, so QRS larger than p wave.



The interval between the onset of the P wave and the onset of the QRS complex is termed the **'PR interval' and largely reflects the duration of AV nodal conduction.**

Injury to the left or right bundle branch delays ventricular depolarisation, widening the QRS complex.

Selective injury of one of the left fascicles affects the electrical axis.

Repolarisation is slower and spreads from the epicardium to the endocardium.

Atrial repolarisation does not cause a detectable signal but ventricular repolarisation produces the T wave.

The QT interval represents the total duration of ventricular depolarisation and repolarisation.

The 12-lead ECG

The 12-lead ECG is generated from 10 electrodes that are attached to the skin. One electrode is attached to each limb and six electrodes are attached to the chest. In addition, the left arm, right arm and left leg electrodes are attached to a central terminal acting as an additional virtual electrode in the centre of the chest (the right leg electrode acts as an earthing electrode). The 12 ‘leads’ of the ECG refer to recordings made from pairs or sets of these electrodes. They comprise three groups: three dipole limb leads, three augmented voltage limb leads and six unipole chest leads.

Leads I, II and III are the dipole limb leads and refer to recordings obtained from pairs of limb electrodes.

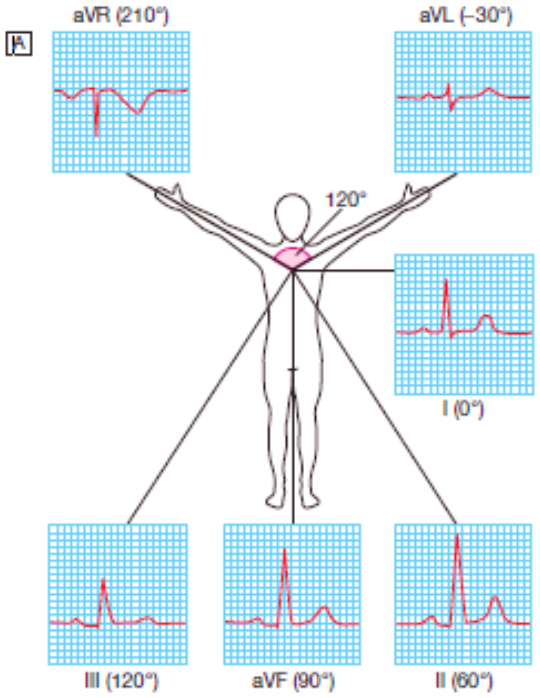
Lead I records the signal between the right (negative) and left (positive) arms. Lead II records the signal between the right arm (negative) and left leg (positive). Lead III records the signal between the left arm (negative) and left leg (positive). These three leads thus record electrical activity along three different axes in the frontal plane. Leads aVR, aVL and aVF are the augmented voltage limb leads. These record electrical activity between a limb electrode and a modified central terminal. For example, lead aVL records the signal between the left arm (positive) and a central (negative) terminal, formed by connecting the right arm and left leg electrodes.

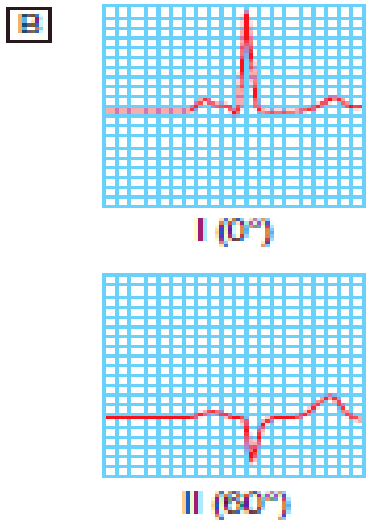
16.2 How to read a 12-lead electrocardiogram: examination sequence

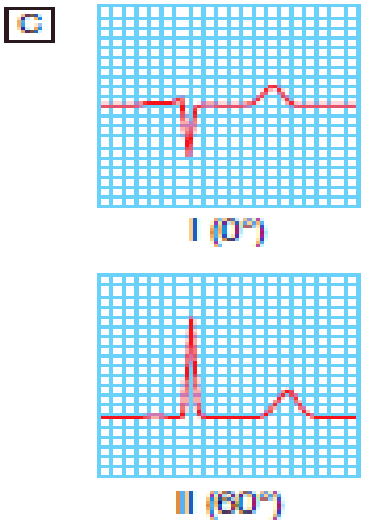
Rhythm strip (lead II)	To determine heart rate and rhythm
Cardiac axis	Normal if QRS complexes +ve in leads I/II
P-wave shape	Tall P waves denote right atrial enlargement (P pulmonale) and notched P waves denote left atrial enlargement (P mitrale)
PR interval	Normal = 0.12–0.20 sec. Prolongation denotes impaired atrioventricular nodal conduction. A short PR interval occurs in Wolff–Parkinson–White syndrome (p. 474)
QRS duration	If > 0.12 sec, ventricular conduction is abnormal (left or right bundle branch block)
QRS amplitude	Large QRS complexes occur in slim young patients and in patients with left ventricular hypertrophy
Q waves	May signify previous myocardial infarction
ST segment	ST elevation may signify myocardial infarction, pericarditis or left ventricular aneurysm; ST depression may signify ischaemia or infarction
T waves	T-wave inversion has many causes, including myocardial ischaemia or infarction, and electrolyte disturbances
QT interval	Normal < 0.42 sec. QT prolongation may occur with congenital long QT syndrome, low K^+, Mg^{2+} or Ca^{2+}, and some drugs (see Box 16.26, p. 476)
ECG conventions	Depolarisation towards electrode: +ve deflection Depolarisation away from electrode: –ve deflection Sensitivity: 10 mm = 1 mV Paper speed: 25 mm per sec Each large (5 mm) square = 0.2 sec Each small (1 mm) square = 0.04 sec Heart rate = 1500/RR interval (mm) (i.e. 300 ÷ number of large squares between beats)

Similarly augmented signals are obtained from the right arm (aVR) and left leg (aVF). These leads also record electrical activity in the frontal plane, with each lead 120˚ apart. Lead aVF thus examines activity along the axis +90˚, and lead aVL along the axis -30˚, and so on.

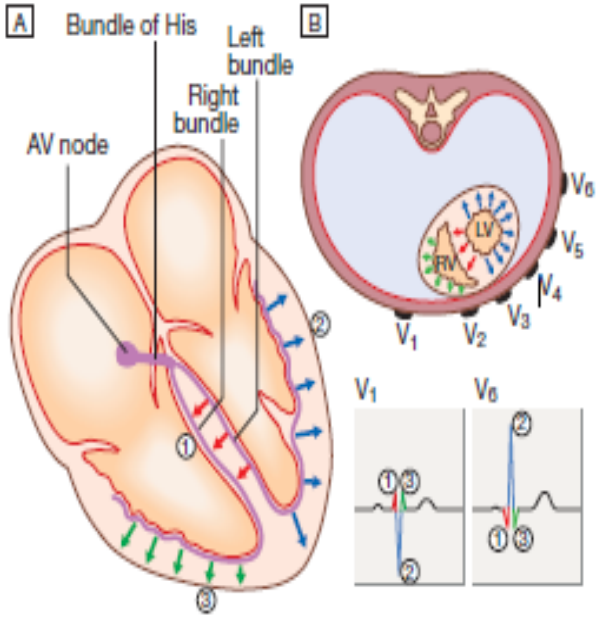
When depolarisation moves towards a positive electrode, it produces a positive deflection in the ECG; depolarisation in the opposite direction produces a negative deflection.







The average vector of ventricular depolarisation is known as the frontal cardiac axis. When the vector is at right angles to a lead, the depolarisation in that lead is equally negative and positive (isoelectric). the QRS complex is isoelectric in aVL, negative in aVR and most strongly positive in lead II; the main vector or axis of depolarisation is therefore 60°. **The normal cardiac axis lies between -30° and +90°.**



Each lead records the signal between the corresponding chest electrode (positive) and the central terminal (negative). Leads V1 and V2 lie approximately over the RV, V3 and V4 over the interventricular septum, and V5 and V6 over the LV . The LV has the greater muscle mass and contributes the major component of the QRS complex.

The shape of the QRS complex varies across the chest leads. **Depolarisation of the interventricular septum occurs first and moves from left to right; this generates a small initial negative deflection in lead V6 (Q wave) and an initial positive deflection in lead V1 (R wave).** The second phase of depolarisation is activation of the body of the LV, which creates a large positive deflection or R wave in V6 (with reciprocal changes in V1). The third and final phase involves the RV and produces a small negative deflection or S wave in V6.

Exercise ECG

In exercise or stress electrocardiography a 12-lead ECG is recorded during exercise on a treadmill or bicycle ergometer. It is similar to a resting ECG, except that the limb electrodes are placed on the shoulders and hips rather than the wrists and ankles. The Bruce Protocol is the most commonly used. During an exercise ECG, BP is recorded and symptoms are assessed. Common indications for exercise testing . **The test is considered positive if angina occurs, BP falls or fails to increase, or if there are ST segment shifts of more than 1 mm .** Exercise testing is useful in confirming the diagnosis of coronary artery disease in patients with suspected angina, and under these circumstances has good sensitivity and specificity .

False-negative results can, however, occur in patients with coronary artery disease, and not all patients with a positive test have coronary disease. This is especially true in low-risk individuals, such as asymptomatic young or middle-aged women, in whom an abnormal response is more likely to represent a false-positive than a true-positive test. Stress testing is contraindicated in the presence of acute coronary syndrome, decompensated heart failure and severe hypertension.

16.3 Exercise testing

Indications

- To confirm the diagnosis of angina
- To evaluate stable angina
- To assess prognosis following myocardial infarction
- To assess outcome after coronary revascularisation, e.g. coronary angioplasty
- To diagnose and evaluate the treatment of exercise-induced arrhythmias

High-risk findings

- Low threshold for ischaemia (within stage 1 or 2 of the Bruce Protocol)
- Fall in blood pressure on exercise
- Widespread, marked or prolonged ischaemic ECG changes
- Exercise-induced arrhythmia

Ambulatory ECG

Ambulatory ECG recordings can be obtained using a portable digital recorder. These devices usually provide limb lead ECG recordings only, on a continuous basis for periods of between 1 and 7 days. The main indication for ambulatory ECG is in the investigation of patients with **suspected arrhythmia, such as those with intermittent palpitation, dizziness or syncope.** In this situation a standard ECG provides only a snapshot of the cardiac rhythm and is unlikely to detect an intermittent arrhythmia, so a longer period of recording is required . Ambulatory ECG can also be used to **assess rate control in patients with atrial fibrillation**, and to **detect transient myocardial ischaemia using ST segment analysis.** If symptoms are infrequent, special recorders can be issued that can be activated by the patient when a symptom episode occurs and placed on the chest wall to record the cardiac rhythm at that point in time. With some devices, the recording can be transmitted to hospital electronically. If the symptoms are very infrequent but potentially serious, such as syncope, **implantable 'loop recorders'** resembling a leadless pacemaker can be used and implanted subcutaneously to record cardiac rhythm for prolonged periods of **between 1 and 3 years.**

Cardiac biomarkers

Several biomarkers are available that can be measured in peripheral blood to assess myocardial dysfunction and ischaemia.

Brain natriuretic peptide

Brain natriuretic peptide (BNP) is a peptide hormone of 32 amino acids with **diuretic properties**. **It is secreted by the LV** as a 108 amino acid prohormone, which is cleaved to produce active BNP, and an inactive 76-amino acid N-terminal fragment (NT-proBNP). Circulating levels are **elevated in conditions associated with LV systolic dysfunction.** Generally, NT-proBNP is measured inpreference to BNP since it has a longer half-life. Measurements of **NT-proBNP are indicated for the diagnosis of LV dysfunction and to assess prognosis and response to therapy in patients with heart failure.**

Cardiac troponins

Troponin I and troponin T are structural cardiac muscle proteins that are released during myocyte damage and necrosis, and represent the cornerstone of the diagnosis of acute myocardial infarction . Modern assays are extremely sensitive, however, and can detect minor degrees of myocardial damage, so that **elevated plasma troponin concentrations may be observed in conditions other than acute MI, such as pulmonary embolus, septic shock and pulmonary oedema.**

Chest X-ray

This is useful for determining the **size and shape of the heart**, and the **state of the pulmonary blood vessels and lung fields**. Most information is given by a postero-anterior (PA) projection taken in full inspiration. Anteroposterior (AP) projections can be performed when patient movement is restricted but result in magnification of the cardiac shadow. An estimate of overall heart size can be made by comparing the maximum width of the cardiac outline with the maximum internal transverse diameter of the thoracic cavity. **The term cardiomegaly is used to describe an enlarged cardiac silhouette when the ratio of cardiac width to the width of the lung fields is greater than 0.5. Cardiomegaly can be caused by chamber dilatation, especially left ventricular dilatation, or by a pericardial effusion, but may also be due to a mediastinal mass or pectus excavatum. Cardiomegaly is not a sensitive indicator of left ventricular systolic dysfunction since the cardiothoracic ratio is normal in many patients with poor left ventricular function and is not specific, since many patients with cardiomegaly on chest X-ray have normal echocardiograms.**

Dilatation of individual cardiac chambers can be recognised by the characteristic alterations to the cardiac silhouette

- **Left atrial dilatation results in prominence of the left atrial appendage, creating the appearance of a straight left heart border, a double cardiac shadow to the right of the sternum, and widening of the angle of the carina (bifurcation of the trachea) as the left main bronchus is pushed upwards.**

- Right atrial enlargement projects from the right heart border towards the right lower lung field.

- Left ventricular dilatation causes prominence of the left heart border and enlargement of the cardiac silhouette.

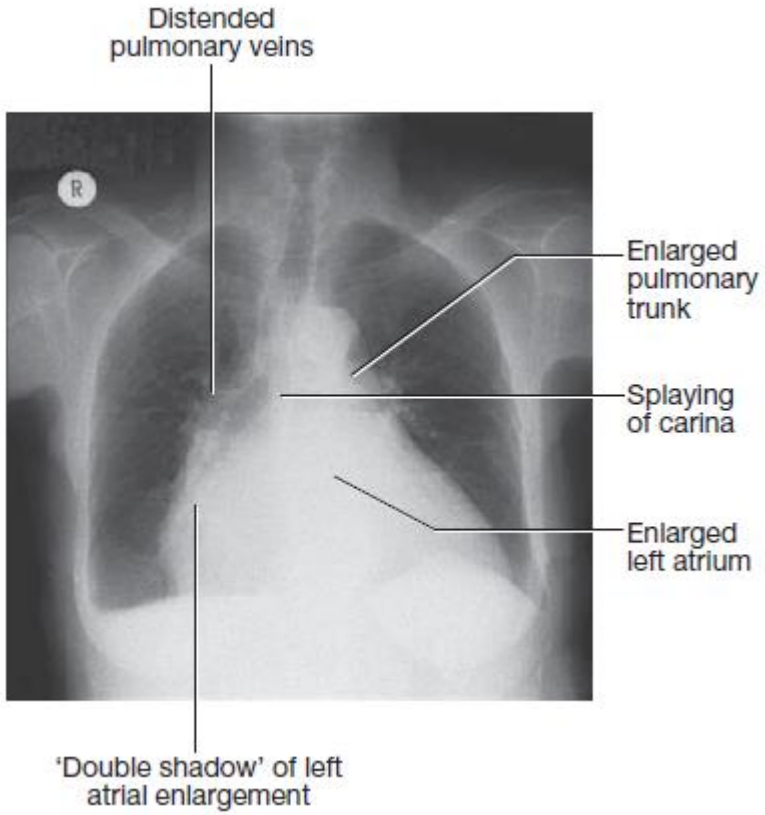
- Left ventricular hypertrophy produces rounding of the left heart border .

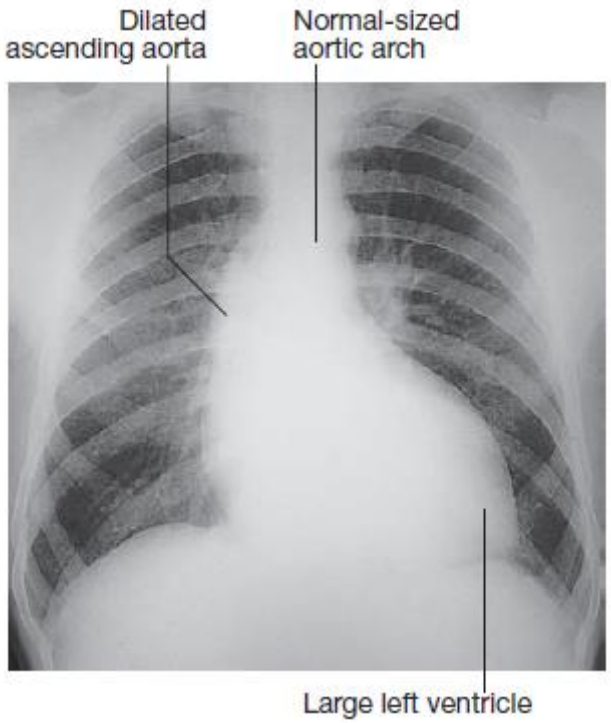
- **Right ventricular dilatation** increases heart size, displaces the apex upwards and **straightens the left heart border**.

Lateral or oblique projections may be useful for detecting pericardial calcification in patients with constrictive pericarditis or a calcified thoracic aortic aneurysm, as these abnormalities may be obscured by the spine on the PA view.

The lung fields on the chest X-ray may show congestion and oedema in patients with heart failure and an increase in pulmonary blood flow ('pulmonary plethora') in those with left-to-right shunt.

Pleural effusions may also occur in heart failure.





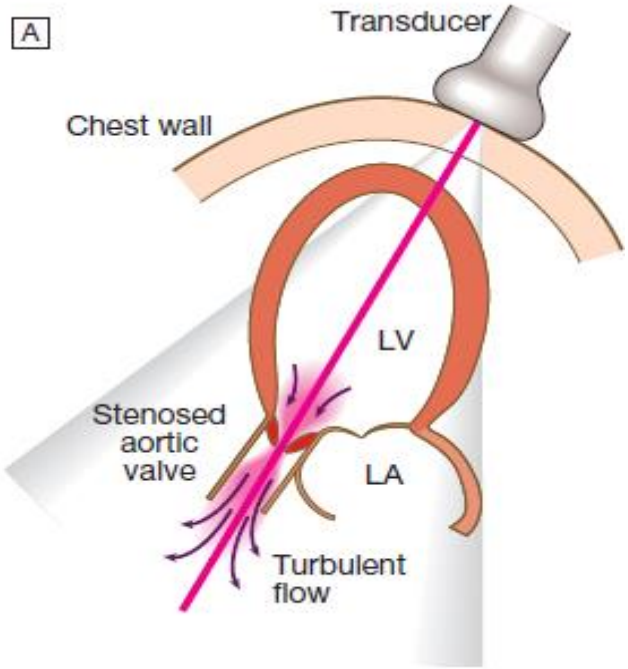
Echocardiography

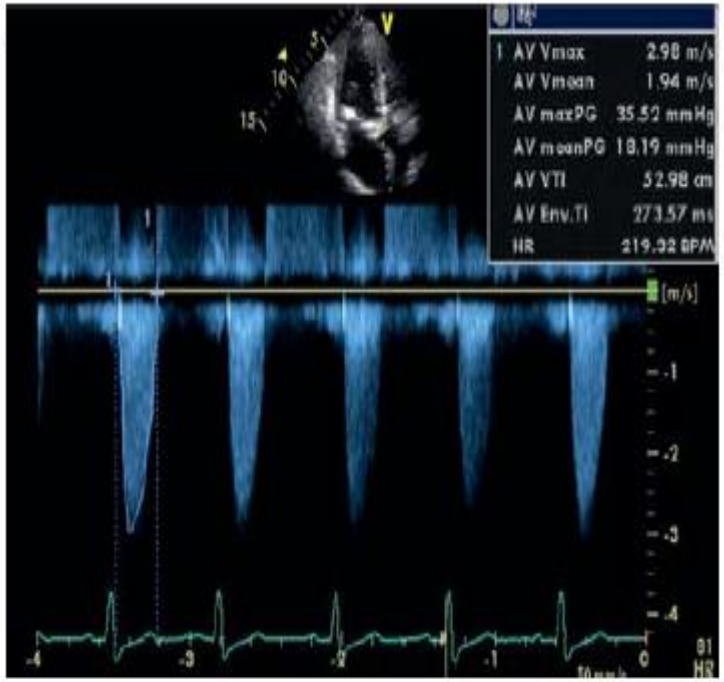
Transthoracic echocardiography

Transthoracic echocardiography, commonly referred to as ‘echo’, is obtained by placing an ultrasound transducer on the chest wall to image the heart structures as a real-time two-dimensional ‘slice’. This can be used for rapid evaluation of various aspects of cardiac structure and function.

16.4 Common indications for echocardiography

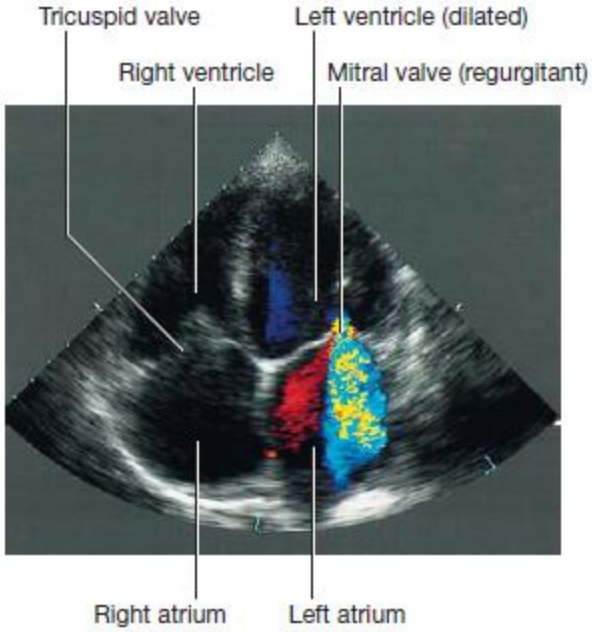
- Assessment of left ventricular function
- Diagnosis and quantification of severity of valve disease
- Identification of vegetations in endocarditis
- Identification of structural heart disease in atrial fibrillation, cardiomyopathies or congenital heart disease
- Detection of pericardial effusion
- Identification of structural heart disease or intracardiac thrombus in systemic embolism


A
Transducer
Chest wall
LV
Stenosed
aortic
valve
LA
Turbulent
flow


AV Vmax 2.98 m/s
AV Vmean 1.94 m/s
AV maxPG 35.52 mmHg
AV meanPG 18.19 mmHg
AV VTI 52.98 cm
AV Env.TI 273.57 ms
HR 219.92 BPM
[m/s]
-1
-2
-3
-4
-4
-3
-2
-1
0
HR

Doppler echocardiography

Doppler echocardiography provides information on blood flow within the heart and the great vessels. It is based on the Doppler principle that sound waves reflected from moving objects, such as red blood cells, undergo a frequency shift. Doppler echocardiography can therefore detect the speed and direction of blood flow in the heart chambers and great vessels. The greater the frequency shift, the faster the blood is moving. The information can be presented either as a plot of blood velocity against time for a particular point in the heart or as



Transoesophageal echocardiography

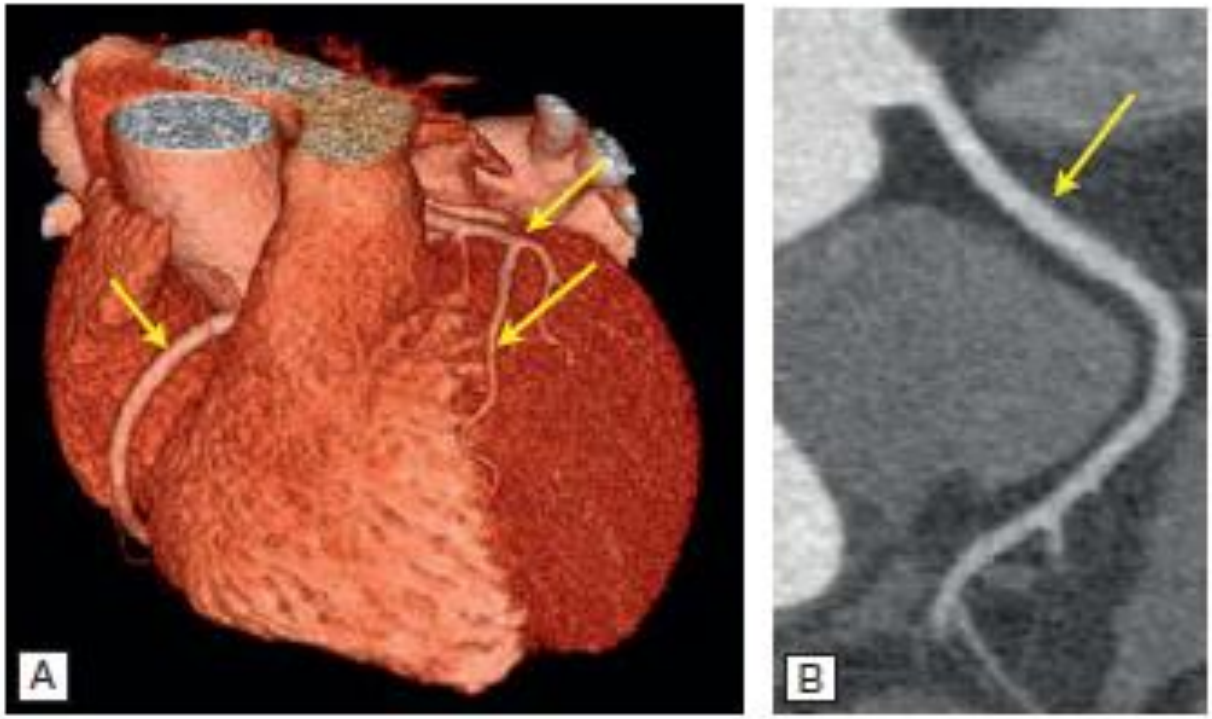
Transoesophageal echocardiography (TOE) involves passing an endoscope-like ultrasound probe into the oesophagus and upper stomach under light sedation and positioning it behind the LA**. It is particularly useful for imaging structures such as the left atrial appendage, pulmonary veins, thoracic aorta and interatrial septum, which may be poorly visualised by transthoracic echocardiography, especially if the patient is overweight or has obstructive airway disease.** The high-resolution images that can be obtained makes TOE particularly valuable for investigating patients with prosthetic (especially mitral) valve dysfunction, congenital abnormalities such as atrial septal defects, aortic dissection, infective endocarditis (vegetations that are too small to be detected by transthoracic echocardiography) and systemic embolism (intracardiac thrombus or masses).

Stress echocardiography

Stress echocardiography is used to investigate patients with suspected coronary artery disease who are unsuitable for exercise stress testing, such as those with mobility problems or pre-existing bundle branch block. A two-dimensional echo is performed before and after infusion of a moderate to high dose of an inotrope, such as dobutamine. Myocardial segments with poor perfusion become ischaemic and contract poorly under stress, manifesting as a wall motion abnormality on the scan. Stress echocardiography is sometimes used to examine myocardial viability in patients with impaired left ventricular function. Low-dose dobutamine can induce contraction in ‘hibernating’ myocardium; such patients may benefit from bypass surgery or percutaneous coronary intervention.

Computed tomography

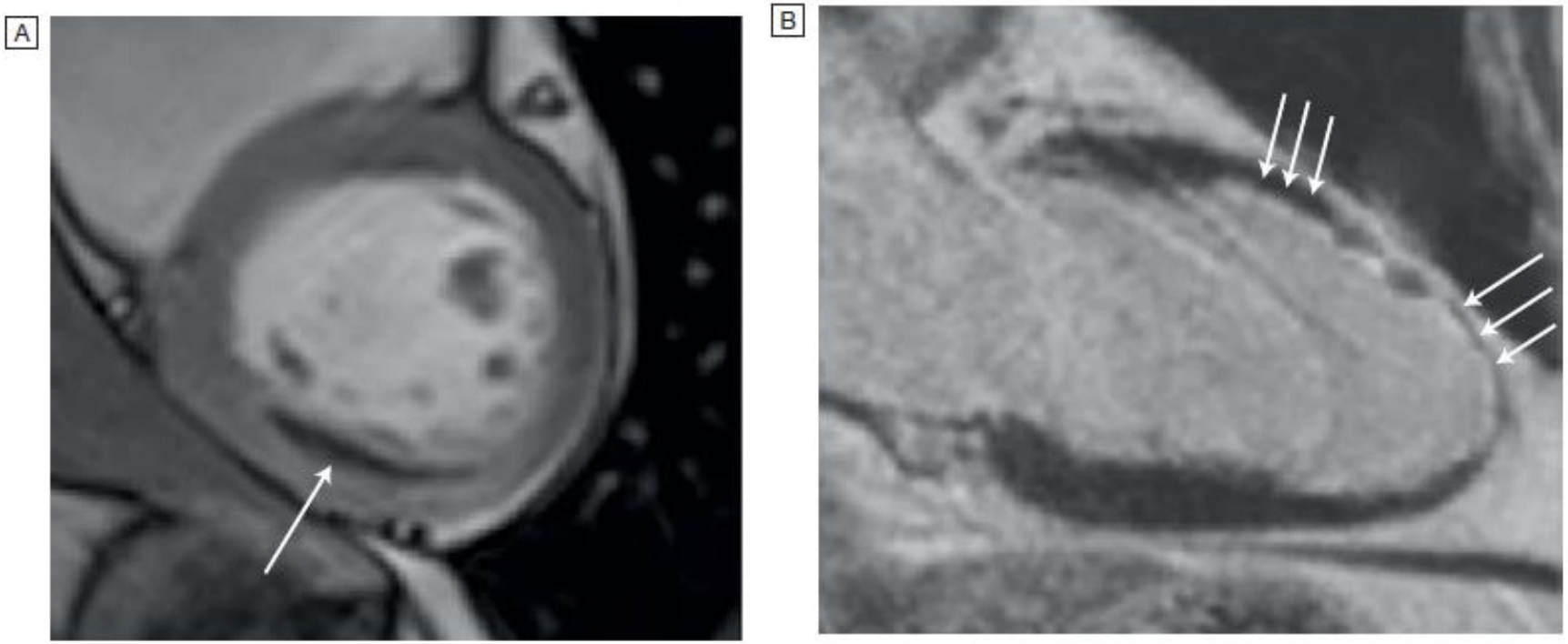
Computed tomography (CT) is useful for imaging the cardiac chambers, great vessels, pericardium, and mediastinal structures and masses. Multidetector scanners can acquire up to 320 slices per rotation, allowing very high-resolution imaging in a single heart beat. CT is often performed using a timed injection of X-ray contrast to produce clear images of blood vessels and associated pathologies. Contrast scans are very useful for imaging the aorta in suspected aortic dissection and the pulmonary arteries and branches in suspected pulmonary embolism. Some centres use **cardiac CT scans for quantification of coronary artery calcification, which may serve as an index of cardiovascular risk.** However, modern multidetector scanning allows non-invasive coronary angiography with a spatial resolution approaching that of conventional coronary arteriography and at a lower radiation dose. CT coronary angiography is particularly useful in the initial **assessment of patients with chest pain and a low or intermediate likelihood of disease, since it has a high negative predictive value in excluding coronary artery disease.** Modern volume scanners are also able to assess myocardial perfusion, often at the same sitting.


A
B

Magnetic resonance imaging

Magnetic resonance imaging (MRI) can be used to generate cross-sectional images of the heart, lungs and mediastinal structures. **It provides better differentiation of soft tissue structures than CT but is poor at demonstrating calcification.** MRI scans need to be ‘gated’ to the ECG, allowing the scanner to produce moving images of the heart and mediastinal structures throughout the cardiac cycle. MRI is very useful for imaging the aorta, including suspected dissection and can define the anatomy of the heart and great vessels in patients with congenital heart disease. It is also useful for detecting infiltrative conditions affecting the heart and for evaluation of the RV that is difficult to image by echocardiography. Physiological data can be obtained from the signal returned from moving blood, which allows quantification of blood flow across regurgitant or stenotic valves. It is also possible to analyse regional wall motion in patients with suspected coronary disease or cardiomyopathy.

Physiological data can be obtained from the signal returned from moving blood, which allows quantification of blood flow across regurgitant or stenotic valves. It is also possible to analyse regional wall motion in patients with suspected coronary disease or cardiomyopathy. Myocardial perfusion and viability can also be readily assessed by MRI. When enhanced by gadolinium-based contrast media, areas of myocardial hypoperfusion can be identified with better spatial resolution than nuclear medicine techniques. Later redistribution of this contrast, so-called delayed enhancement, can be used to identify myocardial scarring and fibrosis: this is a particular strength of cardiac MRI. This can help in selecting patients for revascularisation procedures, or in identifying those with myocardial infiltration, such as that seen with sarcoid heart disease and arrhythmogenic right ventricular cardiomyopathy.

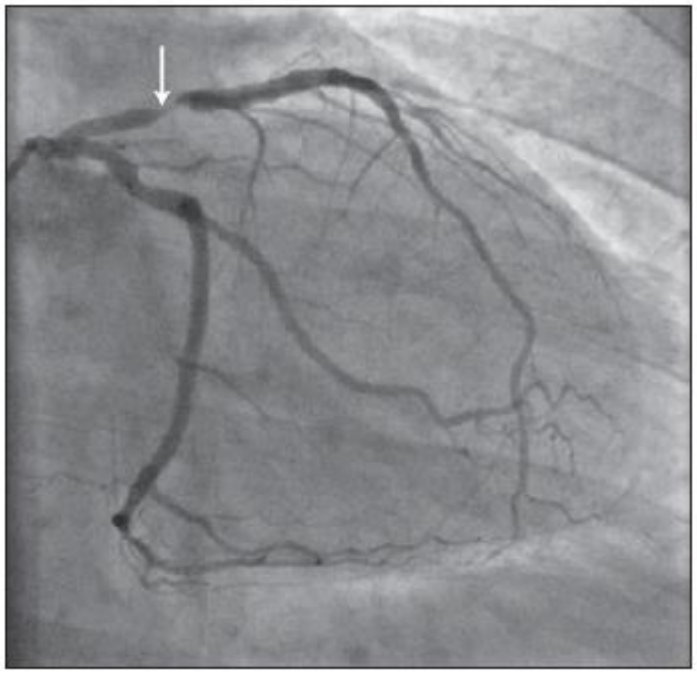

A
B

Cardiac catheterisation

This involves passing a specialised catheter through a peripheral vein or artery into the heart under X-ray guidance. Cardiac catheterisation allows BP and oxygen saturation to be measured in the cardiac chambers and great vessels, and is used to perform angiograms by injecting contrast media into a chamber or blood vessel. Left heart catheterisation involves accessing the arterial circulation, usually through the radial artery, to allow catheterisation of the aorta, LV and coronary arteries. Coronary angiography is the most widely performed procedure, in which the left and right coronary arteries are selectively imaged, providing information about the extent and severity of coronary stenoses, thrombus and calcification. Additional anatomical

(intravascular ultrasound, optical coherence tomography) or functional (pressure wire) assessments are sometimes used to define plaque characteristics and severity more precisely. This permits planning of percutaneous coronary intervention and coronary artery bypass graft surgery. Left ventriculography can be performed during the procedure to determine the size and function of the LV and to demonstrate mitral regurgitation. Aortography defines the size of the aortic root and thoracic aorta, and can help quantify aortic regurgitation. Left heart catheterisation is a day-case procedure and is relatively safe, with serious complications occurring in only approximately 1 in 1000 cases. Right heart catheterisation is used to assess right heart and pulmonary artery pressures, and to detect intracardiac shunts by measuring oxygen saturations in different chambers. For example, a step up in oxygen saturation from 65% in the RA to 80% in the pulmonary artery is indicative of a large left-to-right shunt that might be due to a ventricular septal defect. Cardiac output can also be measured using thermodilution techniques. Left atrial pressure can be measured directly by puncturing the interatrial septum from the RA with a special catheter.

A



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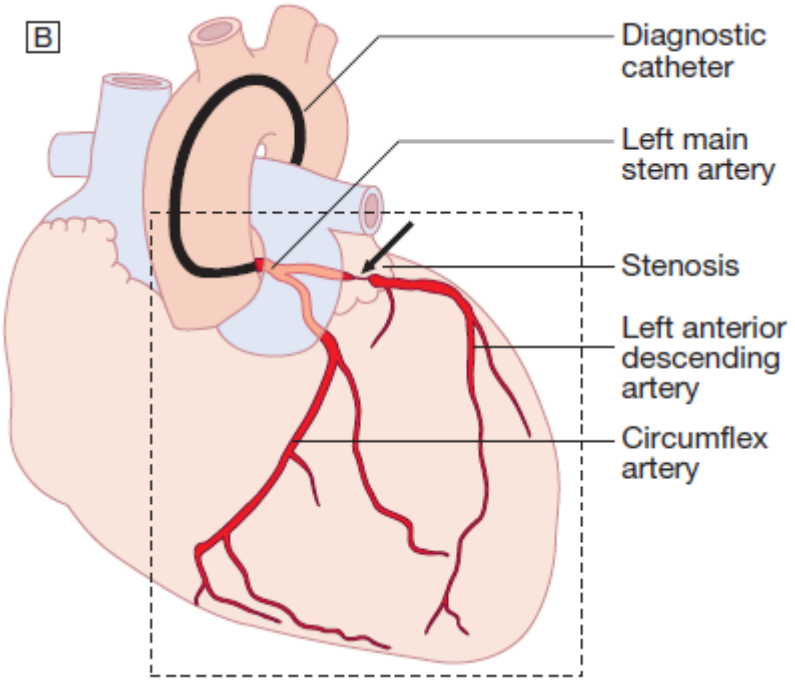
Diagnostic catheter
Left main stem artery
Stenosis
Left anterior descending artery
Circumflex artery

For most purposes, however, a satisfactory approximation to left atrial pressure can be obtained by ‘wedging’ an end-hole or balloon catheter in a branch of the pulmonary artery. Swan–Ganz balloon catheters are often used to monitor pulmonary ‘wedge’ pressure as a guide to left heart filling pressure in critically ill patients.

Electrophysiology

Patients with known or suspected arrhythmia are investigated by percutaneous placement of electrode catheters into the heart via the femoral and neck veins. An electrophysiology study (EPS) is most commonly performed to evaluate patients for catheter ablation and is normally done at the same time as the ablation procedure.

EPS is occasionally used for risk stratification of patients suspected of being at risk of ventricular arrhythmias.

Radionuclide imaging

Radionuclide imaging can be used to evaluate cardiac function but is declining in popularity due to the availability of MRI, which does not involve exposure to radiation and provides equivalent or superior quality data to radionuclide imaging.

Blood pool imaging

The patient is given an intravenous injection of radioisotopelabelled blood cells, and after 4–5 minutes the distribution of isotope in the heart is evaluated by a gamma camera at different phases of the cardiac cycle, thereby permitting the calculation of ventricular ejection fractions. It also allows the assessment of the size and ‘shape’ of the cardiac chambers.

Myocardial perfusion scanning

The patient is given an intravenous injection of a radioactive isotope, such as 99technetium tetrofosmin, and scintiscans of the myocardium are subsequently obtained by gamma camera at rest and during stress. Either exercise stress or pharmacological stress (using the inotrope dobutamine or the vasodilator dipyridamole) can be used. More sophisticated quantitative information can be obtained with positron emission tomography (PET), which can also be used to assess myocardial metabolism, but this is available in only a few centres.