1

What the ECG is about

ECG stands for electrocardiogram, or electrocardiograph. In some countries, the abbreviation used is 'EKG'. Remember:

- By the time you have finished this book, you should be able to say 'The ECG is easy to understand'.
- Most abnormalities of the ECG are amenable to reason.

WHAT TO EXPECT FROM THE ECG

Clinical diagnosis depends mainly on a patient's history, and to a lesser extent on the physical examination. The ECG can provide evidence to support a diagnosis, and in some cases it is crucial for patient management. It is, however, important to see the ECG as a tool, and not as an end in itself.

The ECG is essential for the diagnosis, and therefore management, of abnormal cardiac rhythms. It helps with the diagnosis of the cause of chest pain, and the proper use of thrombolysis in treating myocardial infarction depends upon it. It can help with the diagnosis of the cause of breathlessness.

With practice, interpreting the ECG is a matter of pattern recognition. However, the ECG can be analysed from first principles if a few simple rules and basic facts are remembered. This chapter is about these rules and facts.

THE ELECTRICITY OF THE HEART

The contraction of any muscle is associated with electrical changes called 'depolarization', and these changes can be detected by electrodes attached to the surface of the body. Since all muscular contraction will be detected, the electrical changes associated with contraction of the heart muscle will only be clear if the patient is fully relaxed and no skeletal muscles are contracting.

Although the heart has four chambers, from the electrical point of view it can be thought of as having only two, because the two atria contract together and then the two ventricles contract together.

The wiring diagram of the heart (Fig. 1.1)

The electrical discharge for each cardiac cycle normally starts in a special area of the right atrium called the 'sinoatrial (SA) node'. Depolarization then spreads through the atrial muscle fibres. There is a delay while the depolarization spreads through another special area in the atrium, the 'atrioventricular node' (also called the 'AV

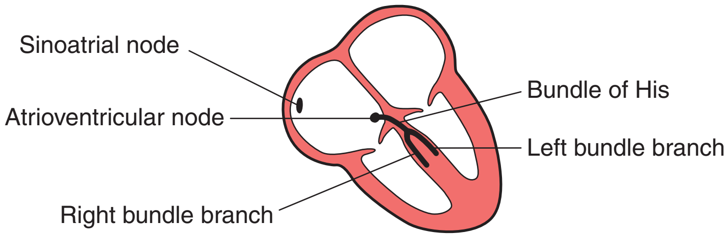


Fig. 1.1 The wiring diagram of the heart

node', or sometimes just 'the node'). Thereafter, the electrical discharge travels very rapidly, down specialized conduction tissue: first a single pathway, the 'bundle of His', which then divides in the septum between the ventricles into right and left bundle branches. The left bundle branch itself divides into two. Within the mass of ventricular muscle, conduction spreads somewhat more slowly, through specialized tissue called 'Purkinje fibres'.

The rhythm of the heart

As we shall see later, electrical activation of the heart can sometimes begin in places other than the SA node. The word 'rhythm' is used to refer to the part of the heart which is controlling the activation sequence. The normal heart rhythm, with electrical activation beginning in the SA node, is called 'sinus rhythm'.

THE SHAPE OF THE ECG

The muscle mass of the atria is small compared with that of the ventricles, and the electrical change accompanying the contraction of the atria is therefore small. Contraction of the atria is associated with the ECG wave called 'P'. The ventricular mass is large, and so there is a large deflection of the ECG when the ventricles are depolarized. This is called the 'QRS' complex. The 'T' wave of the ECG is associated with the return of the ventricular mass to its resting electrical state ('repolarization').

The basic shape of the normal ECG is shown in Figure 1.2.

The letters P, Q, R, S and T were selected in the early days of ECG history, and were chosen arbitrarily. The P, Q, R, S and T deflections are all called waves; the Q, R and S waves together make up a complex; and the interval between the S wave and the T wave is called the ST 'segment'.

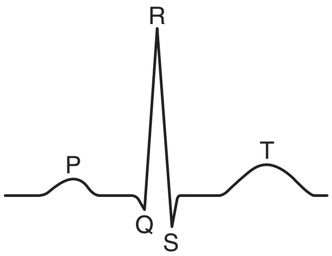


Fig. 1.2 Basic shape of the normal ECG

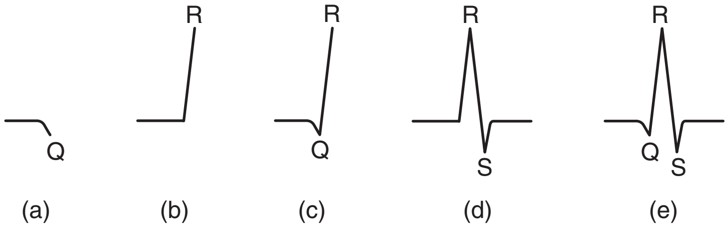


Fig. 1.3 Parts of the QRS complex. (a) Q wave. (b, c) R waves. (d, e) S waves

The different parts of the QRS complex are labelled as shown in Figure 1.3. If the first deflection is downward, it is called a Q wave (Fig. 1.3a). An upward deflection is called an R wave (Fig. 1.3b) – whether it is preceded by a Q wave or not (Fig. 1.3c). Any deflection below the baseline following an R wave is called an S wave (Fig. 1.3d) – whether there has been a preceding Q wave or not (Fig. 1.3e).

Times and speeds

ECG machines record changes in electrical activity by drawing a trace on a moving paper strip. All ECG machines run at a standard rate and use paper with standard-sized squares. Each large square (5 mm) represents 0.2 seconds (s), or 200 milliseconds (ms), so there are five large squares per second, and 300 per minute (min). So an ECG event, such as a QRS complex, occurring once per large square is occurring at a rate of 300/min (Fig. 1.4). The heart rate

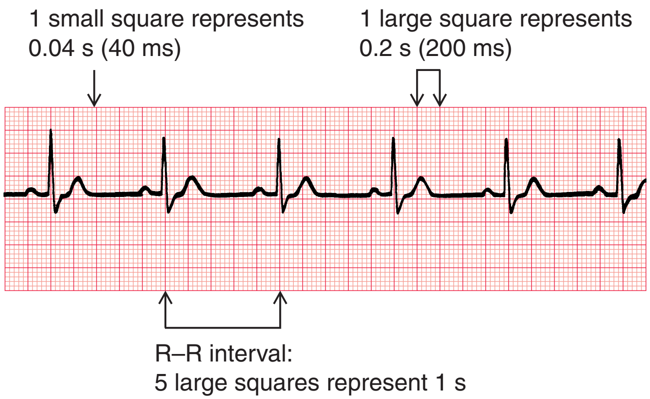


Fig. 1.4 Relationship between the squares on ECG paper and time. Here, there is one QRS complex per second, so the heart rate is 60 beats/min

Table 1.1 Relationship between the number of large squares covered by the R–R interval and the heart rate

R–R interval (large squares)	Heart rate (beats/min)
1	300
2	150
3	100
4	75
5	60
6	50

can be calculated rapidly by remembering the sequence in Table 1.1.

Just as the length of paper between R waves gives the heart rate, so the distance between the different parts of the P–QRS–T complex shows the time taken for conduction of the electrical discharge to spread through the different parts of the heart.

The PR interval is measured from the beginning of the P wave to the beginning of the QRS complex, and is the time taken for excitation to spread from the SA node, through the atrial muscle and the AV node, down the bundle of His and into ventricular muscle.

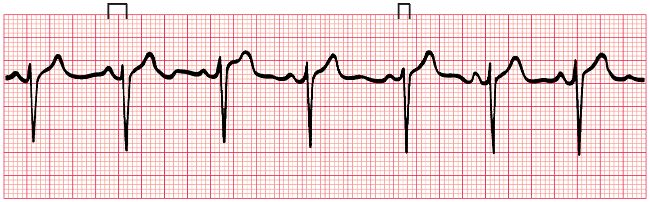


Fig. 1.5 Duration of the PR interval

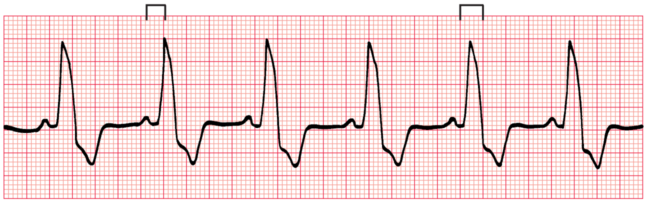


Fig. 1.6 Duration of the QRS complex

The normal PR interval is 0.12–0.2 s (120–200 ms), represented by three to five small squares. Most of the time is taken up by delay in the AV node (Fig. 1.5). If the PR interval is very short, either the atria have been depolarized from close to the AV node, or there is abnormally fast conduction from the atria to the ventricles.

The duration of the QRS complex shows how long excitation takes to spread through the ventricles. The QRS duration is normally 0.12 s (120 ms) (represented by three small squares) or less, but any abnormality of conduction takes longer, and causes widened QRS complexes (Fig. 1.6).

RECORDING AN ECG

The word ‘lead’ sometimes causes confusion. Sometimes it is used to mean the pieces of wire that connect the patient to the ECG recorder. Properly, a lead is an electrical picture of the heart.

The electrical signal from the heart is detected at the surface of the body through five electrodes, which are joined to the ECG recorder by wires. One electrode is attached to each limb, and one is held by suction to the front of the chest and moved to different positions. Good electrical contact between the electrodes and skin is essential. It may be necessary to shave the chest.

The ECG recorder compares the electrical activity detected in the different electrodes, and the electrical picture so obtained is called a 'lead'. The different comparisons 'look at' the heart from different directions. For example, when the recorder is set to 'lead I' it is comparing the electrical events detected by the electrodes attached to the right and left arms. Each lead gives a different view of the electrical activity of the heart, and so a different ECG pattern. Strictly, each ECG pattern should be called 'lead ...', but often the word 'lead' is omitted.

It is not necessary to remember which electrodes are involved in which leads, but it is essential that the electrodes are properly attached, with the wires labelled 'LA' and 'RA' connected to the left and right arms, respectively, and those labelled 'LL' and 'RL' to the left and right legs, respectively. As we shall see, the ECG is made up of characteristic pictures, and the record as a whole is almost uninterpretable if the electrodes are wrongly attached.

The 12-lead ECG

ECG interpretation is easy if you remember the directions from which the various leads look at the heart. The six 'standard' leads, which are recorded from the electrodes attached to the limbs, can be thought of as looking at the heart in a vertical plane (i.e. from the sides or the feet) (Fig. 1.7).

Leads I, II and VL look at the left lateral surface of the heart, leads III and VF at the inferior surface, and lead VR looks at the right atrium.

The V leads are attached to the chest wall by means of a suction electrode, and recordings are made from six

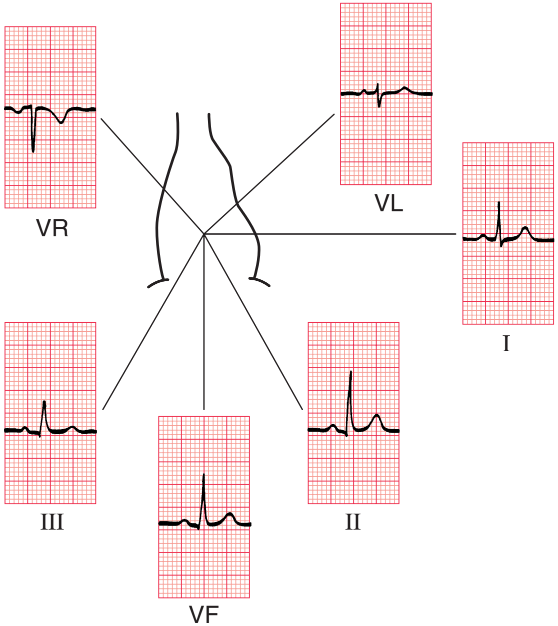


Fig. 1.7 The ECG patterns recorded by the six 'standard' leads

positions, overlying the fourth and fifth rib spaces as shown in Figure 1.8.

The six numbered V leads look at the heart in a horizontal plane, from the front and the left side (Fig. 1.9).

Thus, leads V_1 and V_2 look at the right ventricle, V_3 and V_4 look at the septum between the ventricles and the anterior wall of the left ventricle, and V_5 and V_6 look at the anterior and lateral walls of the left ventricle. As with the limb leads, the chest leads each show a different ECG pattern (Fig. 1.10). In each lead the pattern is characteristic, being similar in different individuals who have normal hearts.

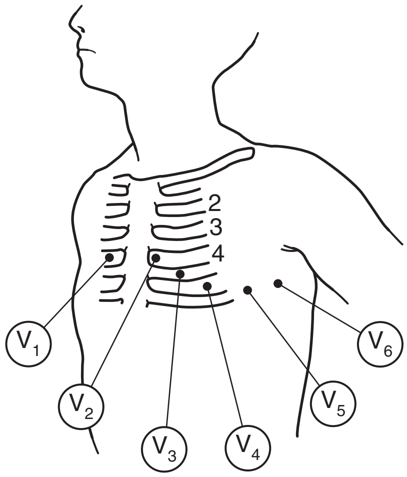


Fig. 1.8 Positioning of the chest V leads. Note that the rib spaces are numbered

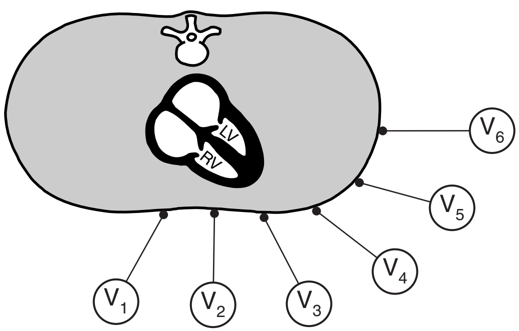


Fig. 1.9 The relationship between the six V leads and the heart

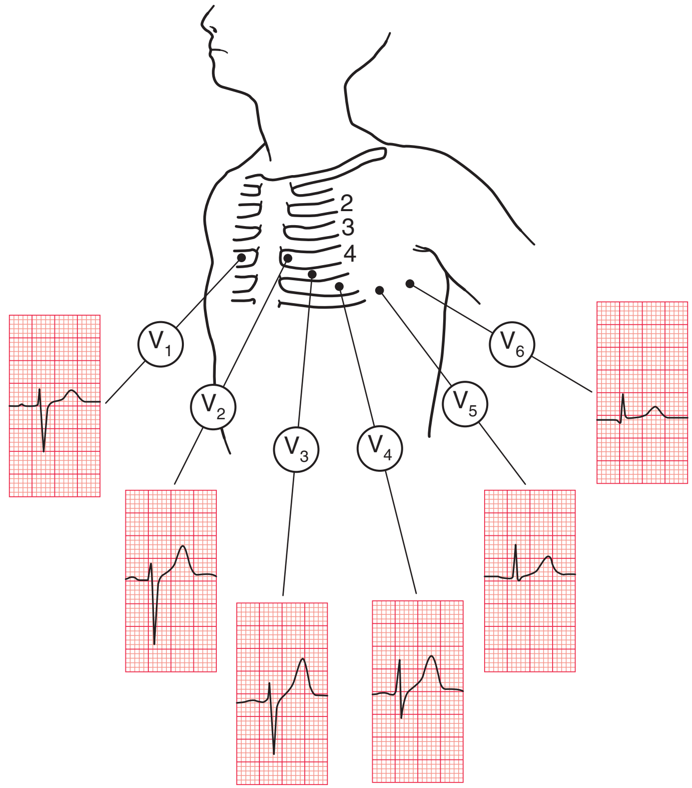


Fig. 1.10 The ECG patterns recorded by the V leads

Calibration

A limited amount of information is provided by the height of the P waves, QRS complexes and T waves, provided the machine is properly calibrated. For example, small complexes may indicate a pericardial effusion, and tall R waves may indicate left ventricular hypertrophy (see Ch. 4). A standard signal of 1 millivolt (mV) should move the stylus

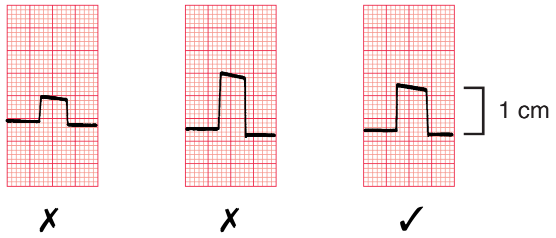


Fig. 1.11 Calibration of the ECG recording

vertically 1 cm (two large squares) (Fig. 1.11), and this 'calibration' signal should be included with every record.

Making a recording

When making a recording:

1. The patient must lie down and relax (to prevent muscle tremor)
2. Connect up the limb electrodes, making certain that they are applied to the correct limb
3. Calibrate the record with the 1 mV signal
4. Record the six standard leads – three or four complexes are sufficient for each
5. Record the six V leads.

THE SHAPE OF THE QRS COMPLEX

We now need to consider why the ECG has a characteristic appearance in each lead.

The QRS complex in the limb leads

The ECG machine is arranged so that when a depolarization wave spreads towards a lead the stylus moves upwards, and when it spreads away from the lead the stylus moves downwards.

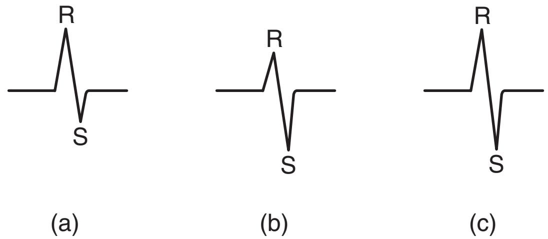


Fig. 1.12 Depolarization and the shape of the QRS complex. Depolarization moving (a) towards the lead, (b) away from the lead and (c) at right angles to the lead

Depolarization spreads through the heart in many directions at once, but the shape of the QRS complex shows the average direction in which the wave of depolarization is spreading through the ventricles (Fig. 1.12).

If the QRS complex is predominantly upward, or positive (i.e. the R wave is greater than the S wave), the depolarization is moving towards that lead (Fig. 1.12a).

If predominantly downward, or negative (S wave greater than R wave), the depolarization is moving away from that lead (Fig. 1.12b).

When the depolarization wave is moving at right angles to the lead, the R and S waves are of equal size (Fig. 1.12c).

Q waves have a special significance, which we shall discuss later.

The cardiac axis

Leads VR and II look at the heart from opposite directions. Seen from the front, the depolarization wave normally spreads through the ventricles from 11 o'clock to 5 o'clock, so the deflections in lead VR are normally mainly downward (negative) and in lead II mainly upward (positive) (Fig. 1.13).

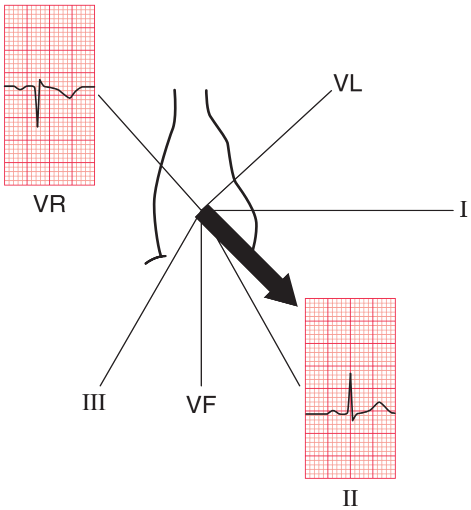


Fig. 1.13 The cardiac axis

The average direction of spread of the depolarization wave through the ventricles as seen from the front is called the 'cardiac axis'. It is useful to decide whether this axis is in a normal direction or not. The direction of the axis can be derived most easily from the QRS complex in leads I, II and III.

A normal 11 o'clock–5 o'clock axis means that the depolarizing wave is spreading towards leads I, II and III and is therefore associated with a predominantly upward deflection in all these leads; the deflection will be greater in lead II than in I or III (Fig. 1.14).

If the right ventricle becomes hypertrophied, the axis will swing towards the right: the deflection in lead I becomes negative (predominantly downward) and the deflection in lead III will become more positive (predominantly upward) (Fig. 1.15). This is called 'right axis deviation'. It is associated mainly with pulmonary conditions that put a strain on the right side of the heart, and with congenital heart disorders.

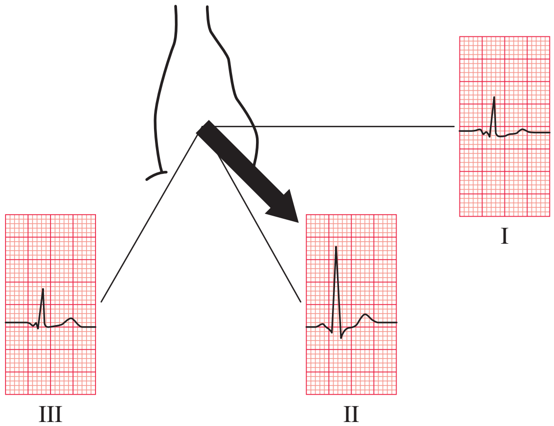


Fig. 1.14 The normal axis

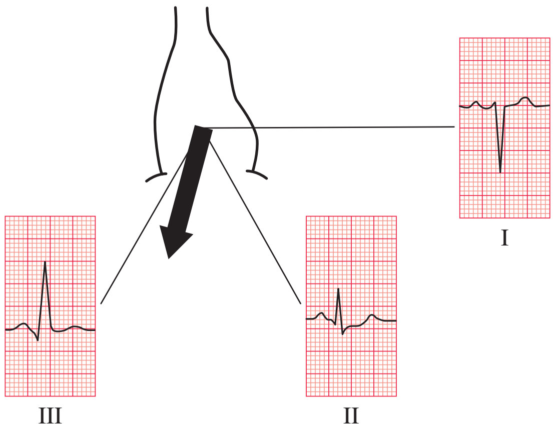


Fig. 1.15 Right axis deviation

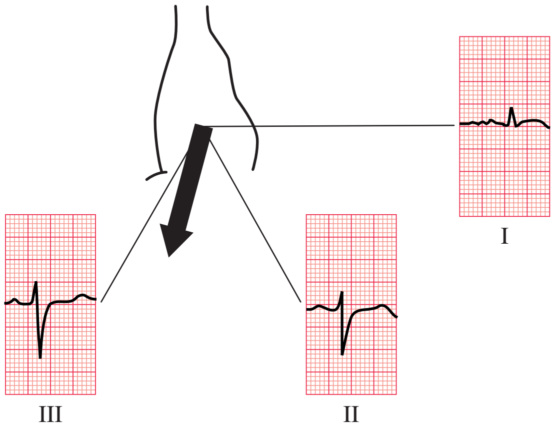


Fig. 1.16 Left axis deviation

When the left ventricle becomes hypertrophied, the axis may swing to the left, so that the QRS complex becomes predominantly negative in lead III (Fig. 1.16). 'Left axis deviation' is not significant until the QRS deflection is also predominantly negative in lead II, and the problem is usually due to a conduction defect rather than to increased bulk of the left ventricular muscle (see Ch. 2).

An alternative explanation of the cardiac axis

Some people find the cardiac axis a difficult concept, and an alternative approach to working it out may be helpful.

The cardiac axis is at right angles (90°) to the lead in which the R and S waves are of equal size (Fig. 1.17).

It is, of course, likely that the axis will not be precisely at right angles to any of the leads, but will be somewhere between two of them. The axis points towards any lead where the R wave is larger than the S wave. It points away from any lead where the S wave is larger than the R wave.

The cardiac axis is sometimes measured in degrees (Fig. 1.18),

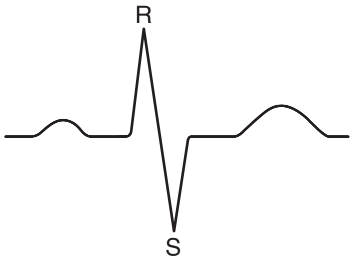


Fig. 1.17 The cardiac axis is at right angles to this lead since the R and S waves are of equal size

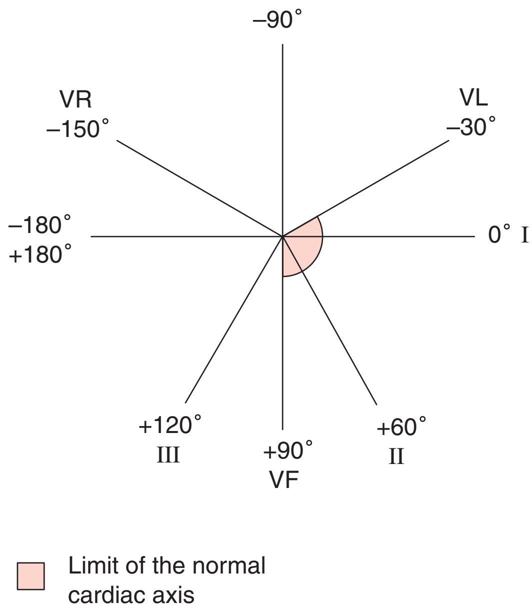


Fig. 1.18 The cardiac axis and lead angle

though this is not clinically particularly useful. Lead I is taken as looking at the heart from 0°; lead II from +60°; lead VF from +90°; and lead III from +120°. Leads VL and VR are said to look from –30° and –150°, respectively.

The normal cardiac axis is in the range –30° to +90°. For example, if in lead II the size of the R wave equals that of the S wave, the axis is at right angles to lead II. In theory, the axis could be at either –30° or +150°. If lead I shows an R wave greater than the S wave, the axis must point towards lead I rather than lead III. Therefore the true axis is at –30° – this is the limit of normality towards what is called the 'left'.

If in lead II the S wave is greater than the R wave, the axis is at an angle of greater than –30°, and left axis deviation is present. Similarly, if the size of the R wave equals that of the S wave in lead I, the axis is at right angles to lead I or at +90°. This is the limit of normality towards the 'right'. If the S wave is greater than the R wave in lead I, the axis is at an angle of greater than +90°, and right axis deviation is present.

Why worry about the cardiac axis?

Right and left axis deviation in themselves are seldom significant – minor degrees occur in long, thin individuals and in short, fat individuals, respectively. However, the presence of axis deviation should alert you to look for other signs of right and left ventricular hypertrophy (see Ch. 4). A change in axis to the right may suggest a pulmonary embolus, and a change to the left indicates a conduction defect.

The QRS complex in the V leads

The shape of the QRS complex in the chest (V) leads is determined by two things:

- The septum between the ventricles is depolarized before the walls of the ventricles, and the depolarization wave spreads across the septum from left to right.

- In the normal heart there is more muscle in the wall of the left ventricle than in that of the right ventricle, and so the left ventricle exerts more influence on the ECG pattern than does the right ventricle.

Leads V_1 and V_2 look at the right ventricle; leads V_3 and V_4 look at the septum; and leads V_5 and V_6 at the left ventricle (see Fig. 1.9).

In a right ventricular lead the deflection is first upwards (R wave) as the septum is depolarized (Fig. 1.19). In a left ventricular lead the opposite pattern is seen: there is a small downward deflection ('septal' Q wave) (Fig. 1.19).

In a right ventricular lead (V_1 and V_2) there is then a downward deflection (S wave) as the main muscle mass is depolarized (Fig. 1.20) – the electrical effects in the bigger left ventricle (in which depolarization is spreading away from a right ventricular lead) outweighing those in the smaller right ventricle (in which depolarization is moving

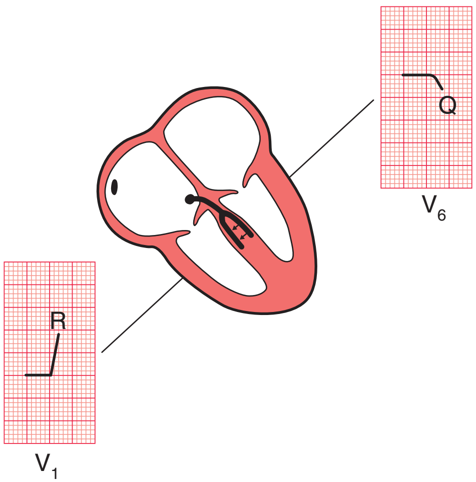


Fig. 1.19 Shape of the QRS complex: first stage

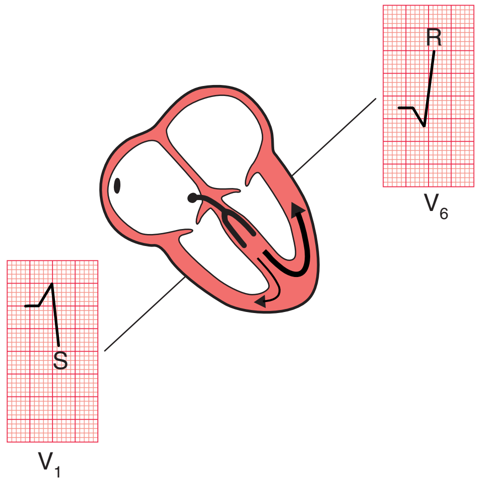


Fig. 1.20 Shape of the QRS complex: second stage

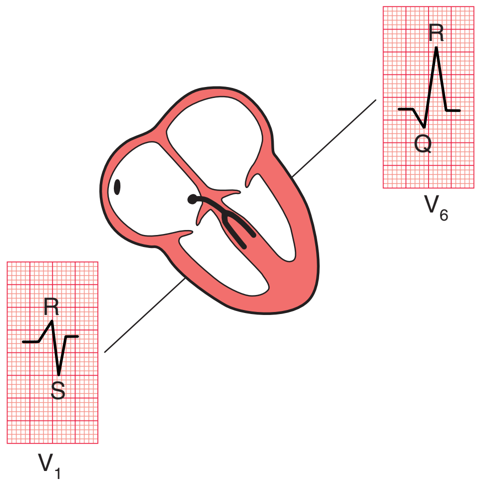


Fig. 1.21 Shape of the QRS complex: third stage

towards a right ventricular lead). In a left ventricular lead there is an upward deflection (R wave) as the ventricular muscle is depolarized (Fig. 1.20).

When the whole of the myocardium is depolarized the ECG returns to baseline (Fig. 1.21).

The QRS complex in the chest leads shows a progression from lead V_1, where it is predominantly downward, to lead V_6, where it is predominantly upward (Fig. 1.22). The

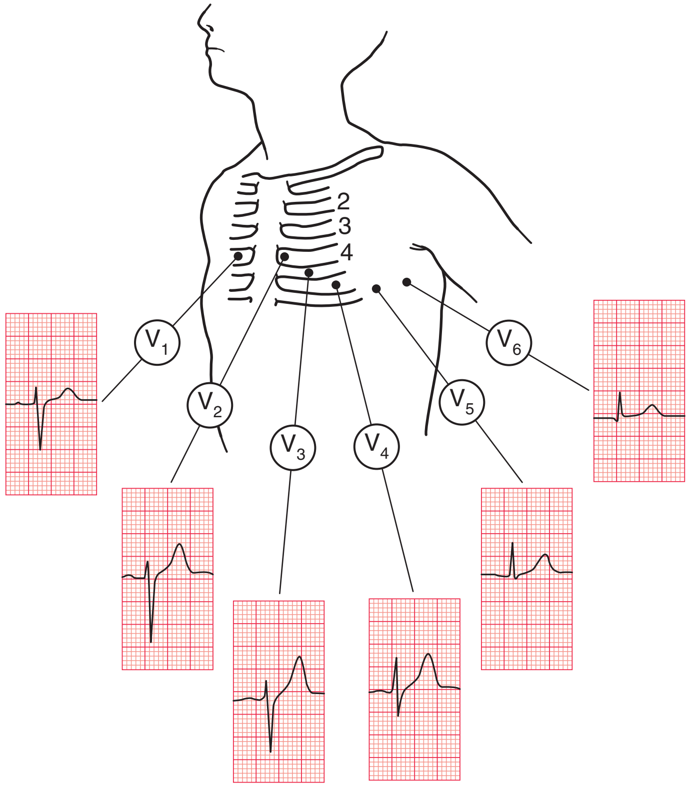


Fig. 1.22 The ECG patterns recorded by the chest leads

'transition point', where the R and S waves are equal, indicates the position of the interventricular septum.

Why worry about the transition point?

If the right ventricle is enlarged, and occupies more of the precordium than is normal, the transition point will move from its normal position of leads V_3/V_4 to leads V_4/V_5 or sometimes leads V_5/V_6. Seen from below, the heart can be thought of as having rotated in a clockwise direction. 'Clockwise rotation' in the ECG is characteristic of chronic lung disease.

HOW TO REPORT AN ECG

You now know enough about the ECG to understand the basis of a report. This should take the form of a description, followed by an interpretation.

The description should always be given in the same sequence:

1. Rhythm
2. Conduction intervals
3. Cardiac axis
4. A description of the QRS complexes
5. A description of the ST segments and T waves.

Reporting a series of totally normal findings is possibly pedantic, and in real life is frequently not done. However, you must think about all the findings every time you interpret an ECG.

ECG INTERPRETATION

The interpretation indicates whether the record is normal or abnormal: if abnormal, the underlying pathology needs to be identified. Examples of 12-lead ECGs are shown in Figures 1.23 and 1.24.

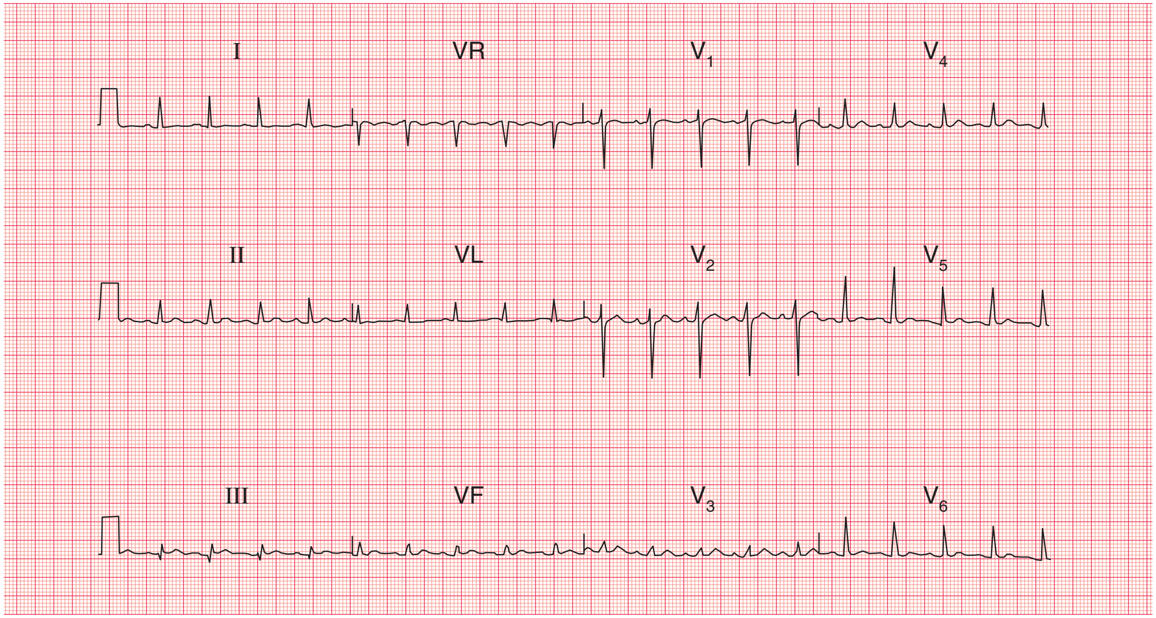


Fig. 1.23 12-lead ECG: example 1

Description

- Sinus rhythm, rate 110/min
- Normal PR interval (140 ms)
- Normal QRS duration (120 ms)
- Normal cardiac axis
- Normal QRS complexes
- Normal T waves (an inverted T wave in lead VR is normal)

Interpretation

- Normal ECG

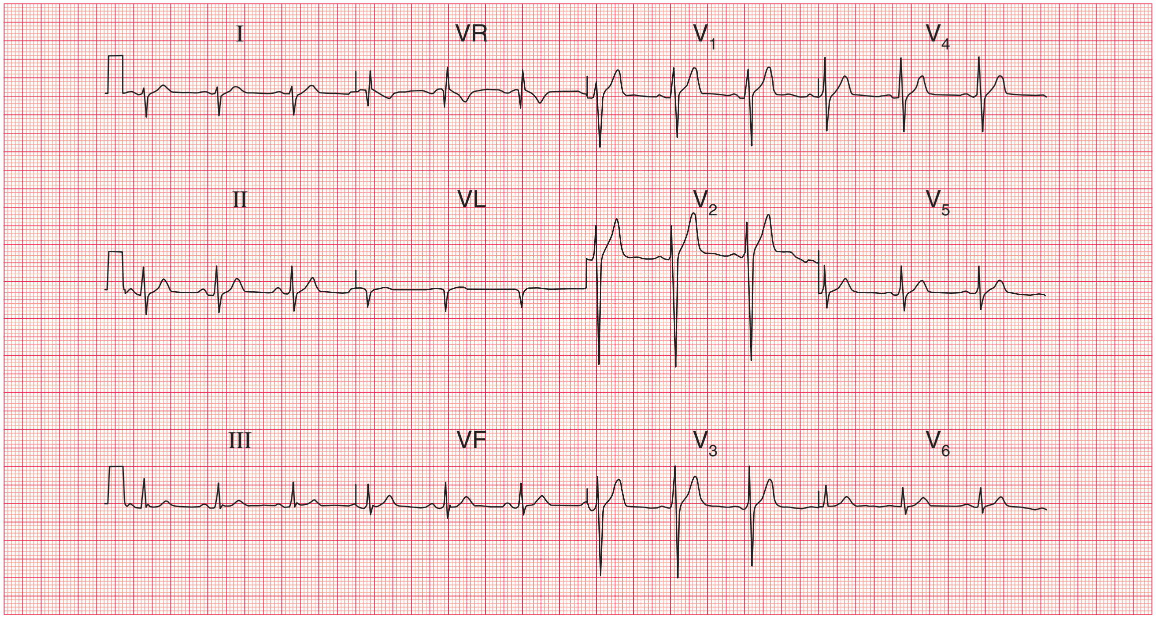


Fig. 1.24 12-lead ECG: example 2

Description

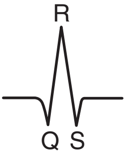
- Sinus rhythm, rate 75/min
- PR interval 200 ms
- QRS duration 120 ms
- Right axis deviation (prominent S wave in lead I)
- Normal QRS complexes
- Normal ST segments and T waves

Interpretation

- Normal ECG – apart from right axis deviation, which could be normal in a tall thin person.
  Unfortunately, there are a lot of minor variations in ECGs which are consistent with perfectly normal hearts. Recognizing the limits of normality is one of the main difficulties of ECG interpretation

THINGS TO REMEMBER

1. The ECG results from electrical changes associated with activation first of the atria and then of the ventricles.
2. Atrial activation causes the P wave.
3. Ventricular activation causes the QRS complex. If the first deflection is downward it is a Q wave. Any upward deflection is an R wave. A downward deflection after an R wave is an S wave.



4. When the depolarization wave spreads towards a lead, the deflection is predominantly upward. When the wave spreads away from a lead, the deflection is predominantly downward.
5. The six limb leads (I, II, III, VR, VL and VF) look at the heart from the sides and the feet in a vertical plane.
6. The cardiac axis is the average direction of spread of depolarization as seen from the front, and is estimated from leads I, II and III.
7. The chest or V leads look at the heart from the front and the left side in a horizontal plane. Lead V_1 is positioned over the right ventricle, and lead V_6 over the left ventricle.
8. The septum is depolarized from the left side to the right.
9. In a normal heart the left ventricle exerts more influence on the ECG than the right ventricle.