# The electrocardiogram 

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#### Abstract

This article describes the features that should be looked at on a 12lead electrocardiogram to determine whether or not it is normal. It describes the abnormalities found in certain conditions, including atrial enlargement, ventricular hypertrophy, acute chest pain, ST elevation myocardial infarction and syncope, with many illustrations.


Keywords Atrial enlargement; Brugada syndrome; cardiovascular disorders; diagnosis; ECG; MRCP; ST elevation myocardial infarction; syncope; ventricular hypertrophy

## The normal electrocardiogram (ECG)

It is important to determine confidently whether an ECG is normal, according to the following parameters (Figure 1):

- The $\mathbf{P}$ wave is 110 ms or less, and 0.25 mV or less; the first two-thirds of the P wave come from right atrial depolarization and the last two-thirds from left atrial depolarization. In health, the P wave is upright in lead II and biphasic in lead V1; the first, positive, deflection is larger than the second, negative, one.
- The PR interval is $140-210 \mathrm{~ms}$. A short PR interval may indicate an accessory pathway, which allows early ventricular depolarization (pre-excitation). A long PR interval reflects slow conduction through the atrioventricular (AV) node and bundle of His, and can indicate disease of the conduction tissue predisposing to bradyarrhythmia through high-grade AV block.
- The QRS axis is normal from $-30^{\circ}$ to $+90^{\circ}$ (Figure 2). The QRS complexes in leads I and II are 'positive' ( R wave $>\mathrm{S}$ wave), and the QRS in lead III is 'negative' ( $S$ wave $>R$ wave). Axis deviation implies either ventricular hypertrophy or disease of one of the left bundle hemifascicles (left axis deviation indicates left anterior hemifascicular block, right axis deviation indicates posterior hemifascicular block).
- The QRS amplitude, when large, implies thin stature or ventricular hypertrophy. When small, it implies obesity, hypothyroidism, pericardial effusion or diffuse loss of myocytes as a result of ischaemic heart disease or cardiomyopathy.

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## Key points

- The ability to interpret an electrocardiogram (ECG) accurately and objectively is an important skill in cardiology
- The recognition of well-defined patterns is the key to safe ECG interpretation
- The QRS duration is 120 ms or less. A broad QRS usually reflects disease of the right, the left or both bundle branches.


## The R wave and S wave

The R wave exhibits normal progression in the chest leads. Its height increases from lead V1 to about V5, and then declines. The S wave increases (becomes deeper) from lead V1 to V2 (sometimes V3), and then declines. The 'transition point' (where the R wave equals the S wave) is usually seen in lead V 3 , and reflects the position of the interventricular septum. The transition point can be moved towards lead V2 in health (clockwise rotation) or towards lead V4 in obesity (anticlockwise rotation). 'Poor R wave progression' (little/no increase in R wave height until lead V4) may indicate an old anterior wall myocardial infarction.

## Non-pathological Q waves

Small Q waves (two small squares or less in amplitude) are seen in lead III (varying with respiration) and laterally in the chest leads, reflecting left-to-right septal depolarization. A large Q wave is seen in lead aVR (as aVR examines the endocardial surface of the heart, it registers the endocardial-to-epicardial spread of depolarization as a Q wave).

## The ST segment

The ST segment is isoelectric. 'Physiological' ST elevation is usually restricted to leads V1-V3/V4.

T wave polarity reflects whether the R or S wave is dominant; if $R$ is greater than $S$, the $T$ wave is upright, and vice versa. Thus, the T wave is normally inverted in leads III, aVF, aVR and V1, and upright elsewhere.

## The QT interval

To determine whether the QT interval is abnormal, it is important to correct for heart rate, as the normal physiological response to increasing heart rate is for the QT interval to shorten. To remove the confounding factor of heart rate, some form of heart rate correction formula is needed so that the dependence of the normal QT interval on heart rate is removed. Fridericia's correction $\left(\mathrm{QT}_{\mathrm{c}}=3 \sqrt{ }(\mathrm{QT} / \mathrm{RR}\right.$ interval) $)$, where RR interval is the interval between QRS complexes measured in seconds (RR interval relates to heart rate by the formula heart rate $=60 / \mathrm{RR}$ interval) is the 'best' heart rate correction formula. All such formulae are, however, scientifically unsound, because they fail


Figure 1 Normal ECG. This is the typical printout with the 12 leads running sequentially in the top three lines. The bottom line is the rhythm strip in this case lead II, But it can be changed to other leads as required.

## Determining the QRS axis



To determine the overall QRS vector, obtain the net difference between the size of the lead $R$ and $S$ wave in I and aVF (i.e. R-S in mV ); then plot this to obtain the overall vector (step 3 - positive numbers plotted rightwards and upwards, and vice versa) that can be measured (step 4) to give the QRS axis. Other leads can be used if these complexes are too small - it is best to choose leads at right angles to each other (e.g. lead aVL and lead II).

Source: P Davey. ECG at a glance. Oxford Wiley-Blackwell, 2008.

Figure 2
to allow for individual QT-heart rate variation with day/night, health/disease and many drugs.

## Right and left atrial enlargement

The ECG is unreliable in the diagnosis of atrial enlargement. The classic signs are as follows (Figure 3). In right atrial enlargement, the P wave height in lead II increases to two and a half small squares or more. In left atrial enlargement, the P wave is dominated by the late, long, left atrial depolarization. This leads to a late second peak in lead II, and a late negative deflection in lead V1 greater than the early positive deflection. V1 is more sensitive than lead II to left atrial enlargement.

## Right and left ventricular hypertrophy

## Right ventricular hypertrophy (RVH)

The ECG is poor at diagnosing RVH/pulmonary hypertension (Figure 4).

- The earliest sign is a rightwards shift in the QRS axis, followed by an increase in the size of the V1 R wave.
- Subsequently, the V1 R wave becomes larger than the S wave (i.e. dominant) (Table 1).
- The T waves in leads V1-V3 invert ('RV strain').
- Finally, right bundle branch block can occur, particularly in acute right heart strain associated with pulmonary embolism.


## Left ventricular hypertrophy (LVH)

- Initially, the R wave height increases in the left-sided standard and chest leads (I, II, aVL and V4-V6), often with commensurate deepening of the S wave in leads V2 and V3.
- The small 'septal' Q waves in lead V5/V6 increase in size with increasing hypertrophy.
- As LVH increases, the QRS axis shifts to the left, and the lateral-lead T waves flatten and then invert ('strain', associated with a worse prognosis in hypertension).
- Finally, the QRS broadens, with the development of complete left bundle branch block.
It is not possible to define a QRS complex size that differentiates normal from LVH. High limits are reliable, but miss most cases; low limits catch many cases, but include many normal subjects. Various scoring systems have been proposed (Table 2).


## Acute chest pain

Acute coronary syndromes (ACSs) result from partial or complete thrombotic occlusion of a coronary artery. The distribution of ECG changes reflects which coronary artery is occluded (Table 3). These changes include:

- T wave flattening
- T wave inversion (Figure 5)
- ST depression (Figure 6; associated with as poor an outlook as ST elevation)
- occasionally, episodes of dynamic ST elevation.


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