2 • The electricity of the heart

For the heart to function efficiently as a 'circulatory pump' it must have a coordinated contraction, the two atria contracting and passing blood into the two ventricles, followed by contraction of the ventricles that push blood out of the heart and into the aorta and pulmonary artery, i.e. there must be a coordinated atrioventricular contraction. In order for the cardiac muscle cells to contract, they must first receive an electrical stimulus. It is this electrical activity that is detected by an ECG.

The electrical stimulus must first depolarise the two atria. Then, after an appropriate time interval, stimulate the two ventricles. The heart must then repolarise (and 'refill') in time for the next stimulus and contraction. Additionally, it must repeatedly do so, increasing in rate with an increase in demand and conversely, slowing at rest.

Formation of the normal P–QRS–T complex

All cells within the heart have the potential to generate their own electrical activity, however the **sinoatrial (SA) node** is the fastest part of the electrical circuit to do so and is therefore the 'rate controller', termed the **pacemaker**. The rate of the SA node is influenced by the balance in autonomic tone, i.e. the sympathetic (increases rate) and parasympathetic (decreases rate) systems.

The electrical discharge for each cardiac cycle (Fig. 2.1) starts in the SA node. Depolarisation spreads through the atrial muscle cells. The depolarisation wave then spreads through the **atrioventricular (AV) node**, but it does so relatively slower, creating a delay. Conduction passes through the AV ring (from the atria into the ventricles) through a narrow pathway called the **bundle of His**. This then divides in the ventricular septum into **left and right bundle branches** (going to the left and right ventricles). The left bundle branch divides further into **anterior and posterior fascicles**. The conduction tissue spreads into the myocardium as very fine branches called **Purkinje fibres**.

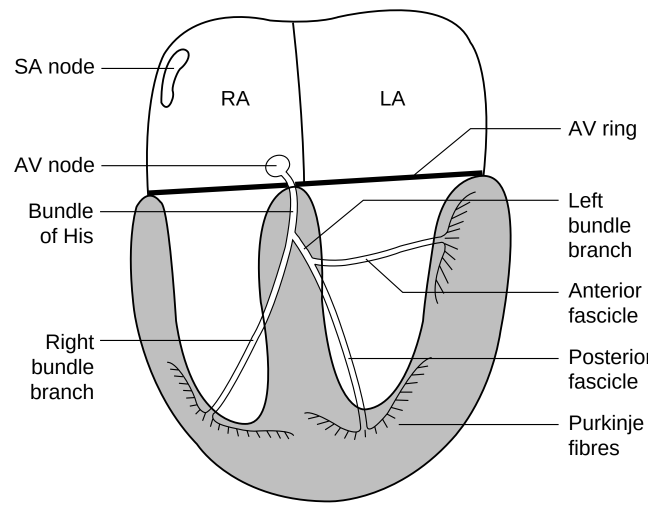

Figure 2.1 Illustration of the heart's electrical circuit. SA – sinoatrial; AV – atrioventricular; RA – right atrium; LA – left atrium.

Formation of the P wave

The SA node is therefore the start of the electrical depolarisation wave. This depolarisation wave spreads through the atria (somewhat like the ripples in water created by dropping a stone into it). As the parts of the atria nearest the SA node are depolarised (Fig. 2.2), this creates an electrical **potential difference** between depolarised atria and parts not yet depolarised (i.e. still in a resting state).

If negative (−ve) and positive (+ve) electrodes were placed approximately in line with those as shown on the diagram (Fig. 2.2), then this would result in the voltmeter (i.e. the ECG machine) detecting the depolarisation wave travelling from the SA node, across the atria, in the general direction of the +ve electrode. On the ECG recording, all positive deflections are displayed as an upward (i.e. positive) deflection on the ECG paper, and negative deflections are displayed downwards. The atrial depolarisation wave therefore creates an upward excursion of the stylus on the ECG paper.

When the whole of the atria become depolarised then there is no longer an electrical potential difference and thus the stylus returns to its idle position – referred to as the **baseline**. The brief upward deflection of the stylus on the ECG paper creates the P wave, representing atrial electrical activity (Fig. 2.3). The muscle mass of the atria is fairly small and thus the electrical changes associated with depolarisation are also small.

The P–R interval

During the course of atrial depolarisation, the depolarisation wave also depolarises the AV node. The speed with which the electrical depolarisation wave travels through the AV node is deliberately slow so that ventricular contraction will be correctly coordinated following atrial contraction. Once the depolarisation wave passes through the AV node, it travels very rapidly through the specialised conduction

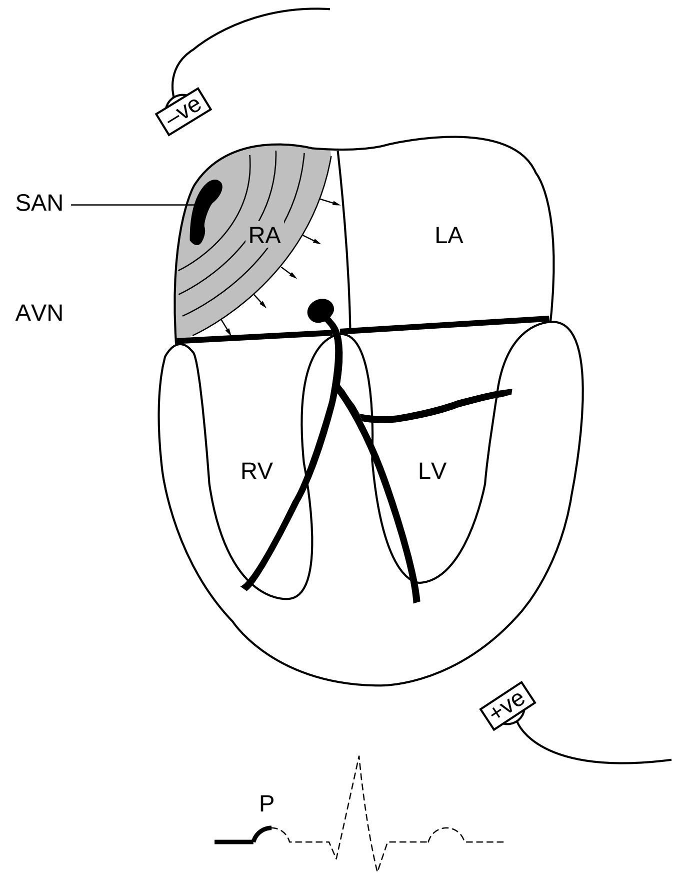

Figure 2.2 Illustration of partial depolarisation of the atria and formation of the P wave. The shaded area represents depolarised myocardial cells; the arrows represent the direction in which the depolarisation wave is travelling. RA – right atrium; LA – left atrium; RV – right ventricle; LV – left ventricle; SAN – sinoatrial node; AVN – atrioventricular node.

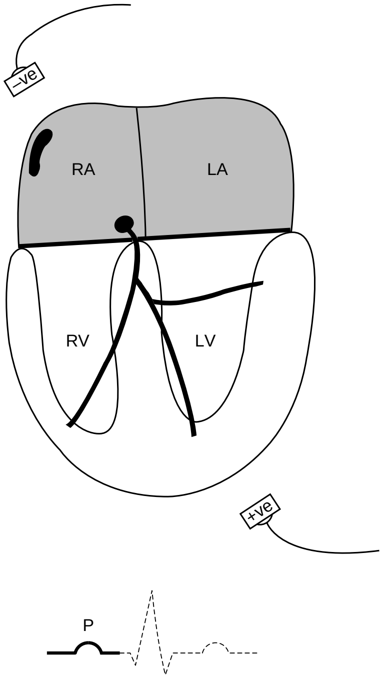

Figure 2.3 Illustration of complete depolarisation of the atria and formation of the P wave. RA – right atrium; LA – left atrium; RV – right ventricle; LV – left ventricle.

tissues of the ventricles, i.e. the bundle of His, the left and right bundle branches and Purkinje fibres.

The formation of the QRS complex

The Q waves

Initially the first part of the ventricles to depolarise is the ventricular septum, with a small depolarisation wave that travels in a direction

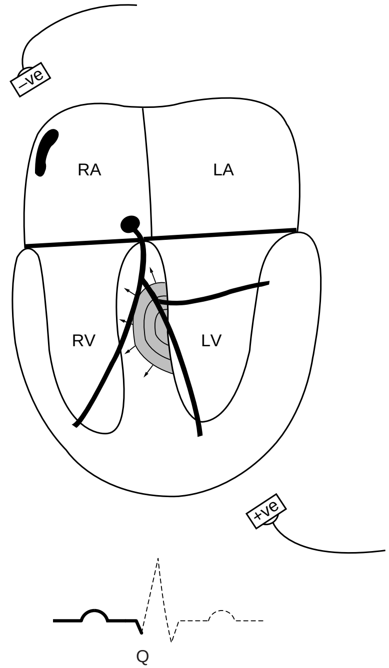

Figure 2.4 Illustration of depolarisation of the ventricular septum and formation of the Q wave. RA – right atrium; LA – left atrium; RV – right ventricle; LV – left ventricle.

away from the +ve electrode (Fig. 2.4). This creates a small downward, or negative, deflection on the ECG paper – termed the Q wave.

The R wave

Then the bulk of the ventricular myocardium is depolarised. This creates a depolarisation wave that travels towards the +ve electrode (Fig. 2.5). As it is a large mass of muscle tissue, it usually creates a large deflection – this is termed the R wave.

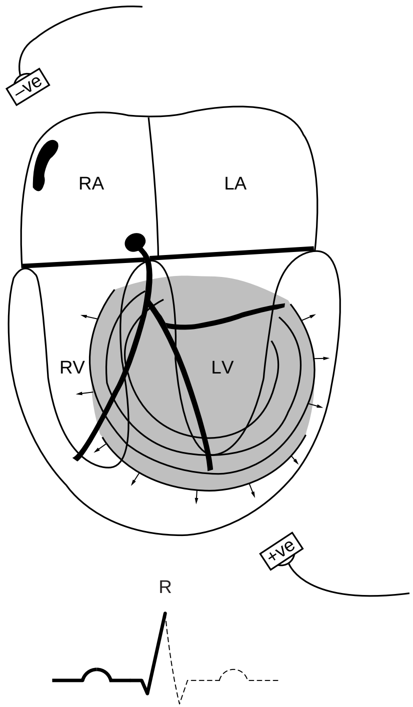

Figure 2.5 Illustration of depolarisation of the bulk of the ventricular myocardium and formation of the R wave. RA – right atrium; LA – left atrium; RV – right ventricle; LV – left ventricle.

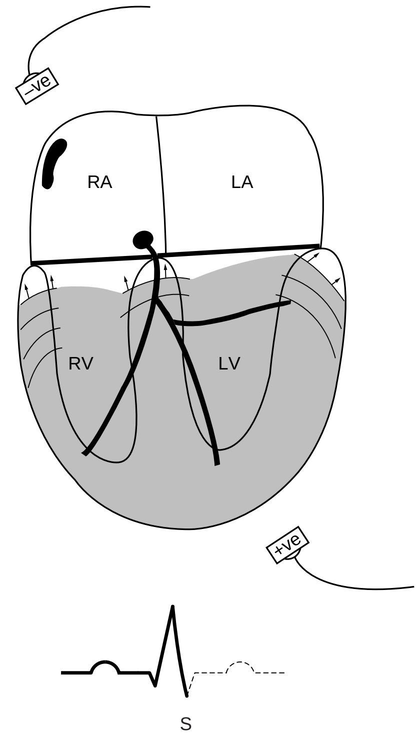

Figure 2.6 Illustration of depolarisation of the basilar portions of the ventricles and formation of the S wave. RA – right atrium; LA – left atrium; RV – right ventricle; LV – left ventricle.

The S wave

Following depolarisation of the majority of the ventricles, the only remaining parts are basilar portions. This creates a depolarisation wave that travels away from the +ve electrode and is a small mass of tissue (Fig. 2.6). Thus, this creates a small negative deflection on the ECG paper – the S wave.

While the different parts of the QRS waveform can be identified, it is often easier to think of the whole ventricular depolarisation waveform as the QRS complex. This will avoid any confusion over the correct and proper naming of the different parts of the QRS complex.

Nomenclature of the QRS complex

The different parts of the QRS complex are strictly and arbitrarily labelled as follows.

- The first downward deflection is called the Q wave; it always precedes the R wave.
- Any upward deflection is called the R wave; it may or may not be preceded by a Q wave.
- Any downward deflection after an R wave is called an S wave, regardless of whether there is a Q wave or not.

Having explained this, it is much easier to think of the 'QRS complex' as a whole, rather than to try to recognise its individual parts.

The T wave

Following complete depolarisation (and contraction) of the ventricles they then repolarise in time for the next stimulus. This phase of repolarisation creates a potential difference across the ventricular myocardium, until it is completely repolarised. This results in a deflection from the baseline – termed the T wave (Fig. 2.7).

The T wave in dogs and cats is very variable, it can be negative or positive or even biphasic (i.e. a bit of both). This is because repolarisation of the myocardium in small animals is a little random, unlike in humans, for example, in which repolarisation is very organised and always results in a positive T wave. Thus, the diagnostic value obtainable from abnormalities in the T wave of small animals is very limited, unlike the very useful features of abnormal T waveforms seen in humans.

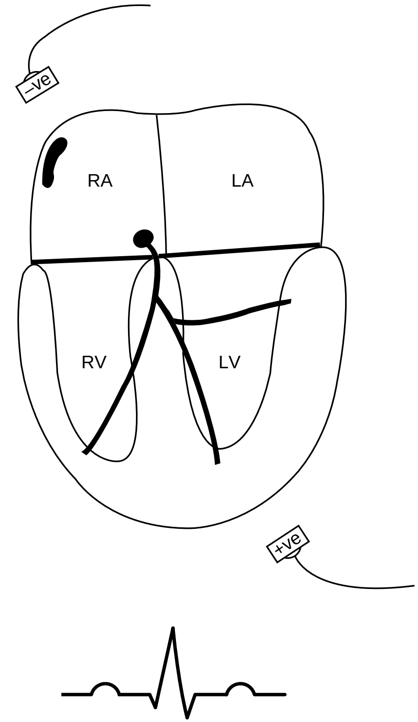

Figure 2.7 Illustration of complete depolarisation and repolarisation of the ventricles and completion of the P–QRS–T complex. RA – right atrium; LA – left atrium; RV – right ventricle; LV – left ventricle.

The repolarisation wave of the atria (T_a) is rarely recognised on a surface ECG, as it is very small and is usually hidden within the QRS complex.