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Anatomy of the conducting system

The conduction system of the heart (Figure 1.1) generates coordinated waves of electrical activity that pass sequentially through the atria and ventricles. The system is required to have an intrinsic ability to generate impulses and direct them through the myocardium. Impulses are generated in the sinoatrial node (SAN), travel in the longitudinal direction of atrial muscle fibres, and then converge on the atrioventricular (AV) node. From the AV node they are funnelled through the His bundle and spread out through the ventricles via the branch bundles. They are delivered to the myocardium by the Purkinje fibres.

Sinoatrial node The SAN is a distinct structure lying within the epicardium at the junction of the superior vena cava (SVC) and right atrium. It is composed of P cells (which have an intrinsic ability to initiate impulses) and transitional cells (which morphologically lie between P cells and atrial myocardium) held within a collagen framework. Conduction fibres extend through the node into the atrium. The node has an autonomic nervous supply and its own arterial branch (the sinoatrial nodal artery) that arises from the right coronary artery in around 55% of people and the left circumflex in 45%.

Atrioventricular node The AV node is a less clearly defined subendocardial structure lying within the atrial septum. Anatomically, it is located at the apex of *Koch*, the borders of which are the coronary sinus os, the tendon of *Todaro*, and the septal leaflet of the tricuspid valve. It

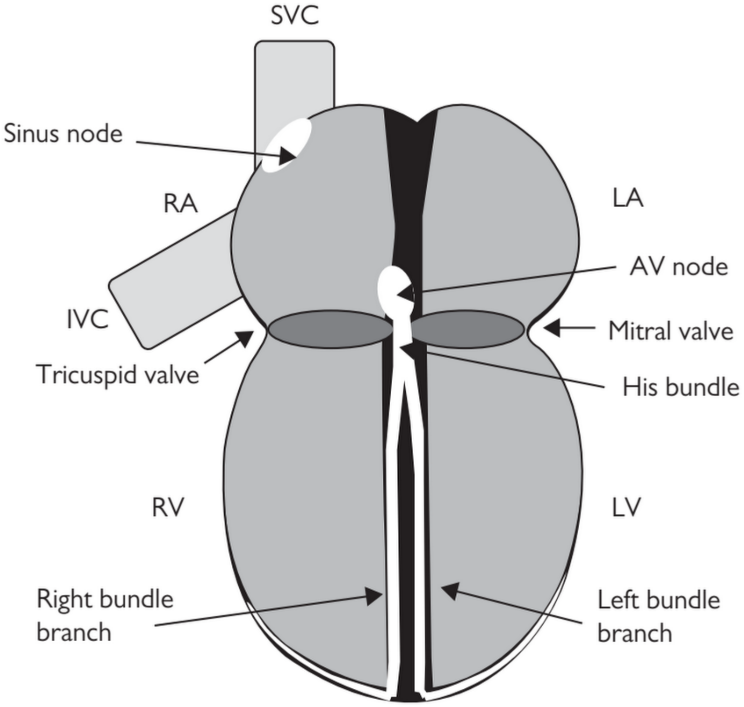

Fig. 1.1 Anatomy of conducting system.

is more loosely composed than the sinus node and contains a variety of atrial, transitional, P, and conduction cells within a collagen network. It has an autonomic nervous supply and its own arterial branch (the AV nodal artery) that arises from the right coronary artery in around 90% of people (left circumflex in the remainder).

His bundle The His bundle joins the AV node to the bundle branches and lies within the membranous septum. It is a tubular bundle of parallel conduction fibres within a collagenous framework. It has minimal nervous supply but arterial supply from the AV nodal artery and septal branches of the left anterior descending artery.

Bundle branches The bundle branches extend from the His bundle through the ventricles. There is significant interindividual variation in the arrangement of these ventricular conduction fibres. However, there is classically a right bundle that extends down the right side of the interventricular septum and a large left bundle that spreads through the LV as two or three distinct tracts. The bundle branches end in the Purkinje network that delivers the electrical impulses to the myocardium. There is minimal autonomic supply but extensive blood supply from all coronary arteries.

Conduction system physiology

The physiology of the conduction system determines the impulse generation and transfer of the electrical activation throughout the myocardium.

Sinoatrial node and atrium

The SAN has significant intrinsic impulse generation capabilities (automaticity) and is the main pacemaker in normal circumstances. The SAN cells generate slow (calcium-driven) action potentials that are then transferred rapidly across the atria via fast (sodium-driven) action potentials. Because of the position of the node the wave of depolarization tends to travel through both atria from superior to inferior.

Atrioventricular node

The AV node is physiologically similar to the SAN, generating slow (calcium-driven) action potentials. Some people have two distinct pathways, or areas, within the node (slow and fast) that are relevant to the generation of supraventricular arrhythmias. The position of the node between atria and ventricles allows it to control passage of electrical impulses to the ventricle. The node delays transfer to allow complete atrial emptying before ventricular contraction and acts as a limit on the rate of ventricular activation in, for example, atrial fibrillation. The node also has some intrinsic automaticity that allows impulse generation.

His bundle and bundle branches

The His bundle has distinct longitudinal fibres that direct electrical impulses to the ventricles. The bundle branches are direct continuations of these fibres. The *His-Purkinje* system facilitates rapid global depolarization through the ventricles, typically producing a narrow QRS complex on the surface electrocardiogram (ECG).

Anatomy of the venous system

Venous access for permanent pacing is usually via the subclavian, cephalic, or axillary veins and for temporary pacing via the subclavian, internal jugular, or femoral veins. See Figure 1.2.

Cephalic vein This is a superficial vein starting from the dorsal venous network of the hand that winds up the radial side of the forearm, over the elbow to the lateral border of biceps. It then passes between the pectoralis major and deltoid muscles in the *delto-pectoral groove* (the access site for pacing). The cephalic vein then joins the axillary vein just below the clavicle.

Axillary vein This is an upper limb deep vein starting as a continuation of the basilic vein at the lower border of teres major. It joins the cephalic vein to form the subclavian vein at the lateral border of the first rib after the cephalic vein.

Subclavian vein This extends to the sternal end of the clavicle where it joins the internal jugular to form the innominate vein. It lies in a groove on the surface of the first rib and pleura where it is accessed for pacing. It has valves around 2 cm from its end.

Internal jugular vein This originates at the base of the skull and drains vertically, lateral to the internal carotid artery and common carotid artery, before joining the subclavian veins to form the innominate veins. Access is usually in the triangle formed by sternal and clavicular heads of sternocleidomastoid.

Innominate vein The right vein is short and passes directly downwards to join the left innominate (a longer vessel passing obliquely across the chest) below the first rib by the right side of the sternum. They join to form the superior vena cava.

Superior vena cava This empties into the right atrium. A *persistent left superior vena cava* is sometimes found. In this situation the venous drainage on the right is normal via a superior vena cava-like structure to the right atrium but there is a separate left-sided drainage, usually to the coronary sinus.

Femoral vein The femoral vein accompanies the femoral artery through the upper two-thirds of the thigh. By the inguinal ligament it lies medial to the artery. The vein continues as the external iliac at the inguinal ligament and joins the hypogastric vein to form the common iliac vein.

Inferior vena cava The inferior vena cava is formed by the union of the left and right common iliac veins usually around the level of the fifth lumbar vertebra. It travels upwards and enters the inferior aspect of the right atrium.

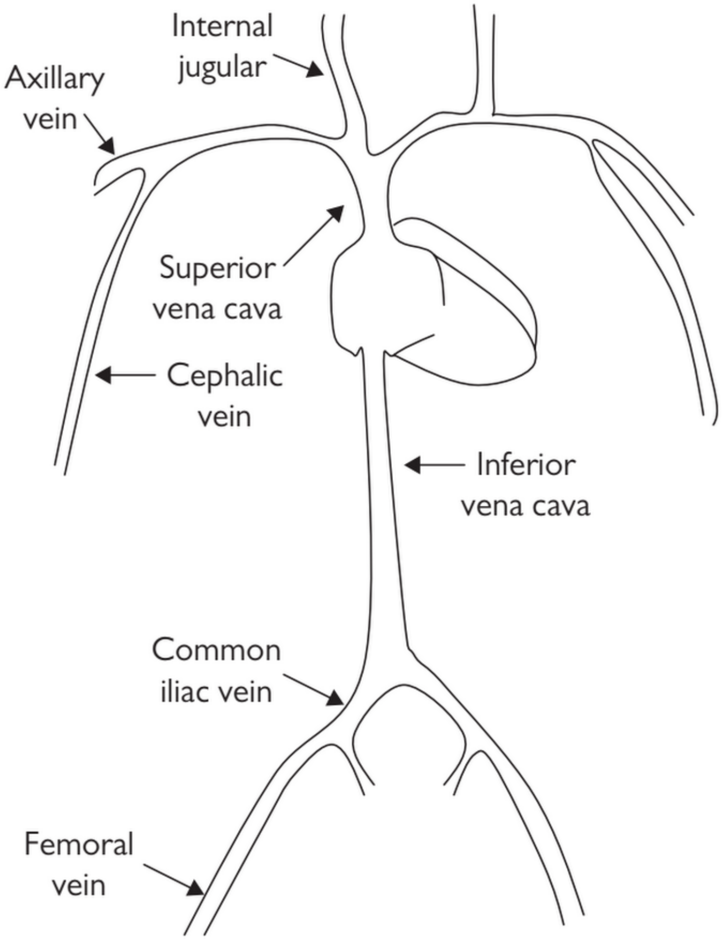

Fig. 1.2 Anatomy of the venous system.

Pacemaker components

The pacemaker consists of a battery and programmed circuitry encased within a metal box that includes external lead connectors.

Battery

The standard battery since the 1970s has been the lithium iodide battery. This battery usually has a median life span of around ten years, although this is affected by the frequency and amplitude of pulse generation. The anode produces lithium ions, and electrons are released, whereas the cathode collects electrons and produces iodide ions. In the centre of the battery these ions combine to form lithium iodide. As lithium iodide builds up it increases internal battery resistance. Eventually the middle layer becomes very thick and the cathode material is depleted, producing the characteristic high-battery impedance that indicates end of battery life (EOL).

Modern devices increasingly use variants of this battery chemistry.

Circuitry

The circuitry defines what each pacemaker can do. Pacemakers are individually designed by the manufacturer to incorporate the necessary pacing and sensing algorithms, as well as a clock and data acquisition functions. The circuitry includes capacitors to generate the impulses and telemetry functions to allow interrogation. A magnet-responsive switch is included for activation of 'magnet mode'. Most pacemakers also have rate response sensors (➔ p. 16).

Case and lead connectors

The generator case is made of titanium and welded together around the battery and circuitry to ensure it is air- and watertight. The connectors are epoxy plastic and fixed on the outside of the case. The details of the pacing device and manufacturer are usually engraved on the outside of the case. The lead connectors are also usually labelled to ensure they are connected correctly.

MRI-conditional devices

It is estimated that two-thirds of people will develop an indication for an MRI scan at some point in their lifetime; this has prompted development of devices that allow MRI scanning. This requires component changes (i.e. to the reed switch) and extensive testing. The first MRI-conditional pacemakers went on the market in 2011 and are rapidly becoming the standard of care, with ICDs and CRT devices following over the next five years. It is vital that instructions are followed—conditionality depends on magnet strength, scanning area, energy, and duration. The device must be temporarily programmed into an MRI mode (asynchronous pacing with therapies, if present, switched off). The whole system must be conditional, that is, no mix of manufacturer between generator and leads, and no leftover hardware from previous systems. Close liaison with the radiology department is recommended in order to develop patient pathways. Further information is available on www.mrisafety.com.

Battery indicators

- EOL: end of life (basic pacemaker functions no longer work).
- ERI: elective replacement indicator (the battery voltage is depleted and close to EOL. Generator replacement should be performed within 2–3 months).

Pacemakers may exhibit diagnostic ERI characteristics when the battery is nearly depleted. These include:

- A fixed decrease in the magnet rate (the rate the pacemaker switches to when a magnet is held over it).
- An increase in the pulse width to compensate for the lower voltage output.
- Change to a simpler pacing mode, for example DDDR to VVI or VOO to reduce battery current drain.

How to increase battery life

- Minimize the amount of pacing required.
- Use pulses with a smaller voltage amplitude.
- Use pulses with a shorter duration/pulse width.
- Use automated capture functions (➔ p. 120).