

CHAPTER 1

Anatomical and Electrophysiological Bases

1.1. The heart walls

The heart has four cavities, two atria and two ventricles, comprised mainly of contractile cells called cardiomyocytes. The electrical stimulus originating in the sinus node (SN) is distributed through the entire heart by means of a specific conduction system (SCS).

A **The left ventricle (LV) has four walls: anterior, septal, inferior, and lateral.** Figure 1.1 shows the three segments of the anterior and inferior walls, the five segments of the septal and lateral walls, and the apex segment (segment 17). Magnetic resonance imaging has now shown that the previously-named posterior wall corresponds to the inferobasal segment of the inferior wall (segment 4 in Fig. 1.1) (Bayés de Luna et al., 2006a; Bayés de Luna A and Fiol-Sala, 2008).

1.2. Coronary circulation (Fig. 1.2)

B Based on coronary perfusion, the heart is divided into two zones: the antero-septal zone, perfused by the left anterior descending artery (LAD) (Fig. 1.2A) and the inferolateral zone, perfused by the right coronary artery (RCA) and circumflex artery (CX) (Figs 1.2C and 1.2D). The heart has areas of shared perfusion (shown in grey in Fig. 1.2A) in which one of the two arteries dominates. For example, segment 17 (apex) is perfused by the

LAD, if long; otherwise by the RCA and even partially by the CX.

1.3. The specific conduction system (Fig. 1.3)

Electrical stimuli pass through the internodal pathways (Bachmann, Wenckebach and Thorel bundles), from the sinus node to the AV node and the His bundle. From there stimuli reach the ventricles through the ventricular conduction system: the right branch (RB) and the trunk of the left branch (LB), and its divisions (superoanterior and inferoposterior fascicles and the middle fibers that exist between them) (Figs 1.3A and 1.3B).

C Figure 1.3C shows in grey the structures that the AV junction encompass. Figure 1.3D shows the three activation entry points in the left ventricle (LV) (Durrer et al., 1970).

1.4. The ultrastructure of cardiac cells

- There are two types of cell in the heart:
 - D** 1. Contractile cells or cardiomyocytes, which are responsible for cardiac pump function (contractile). Under normal conditions these cells do not have automatic capacity and cannot generate stimuli.

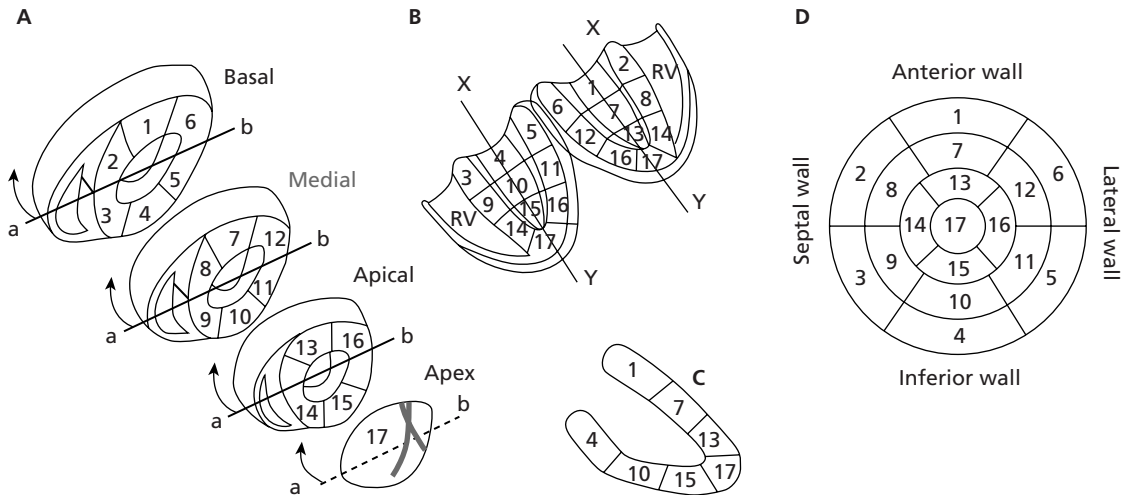


Figure 1.1 (A) Segments into which the left ventricle is divided according to the transverse (short-axis) sections performed at the basal (B), medial (M), and apical (A) levels. The basal and medial sections delineate into six segments each, while the apical section shows four segments. Together with the apex, they constitute the 17 segments into which the left ventricle can be divided, according to the classification performed by the American Imaging Societies (Cerqueira et al., 2002). Also shown is the view of the 17 segments with the heart open in a horizontal long-axis plane (B) and vertical long-axis (sagittal-like) plane (C). In D, the 17 segments and the four walls of the heart are shown in a 'bull's-eye view'. RV = right ventricle.

2. Specific cells (cells of specific system of conduction), which are in charge of impulse formation (automaticity) and impulse transmission to the contractile myocardium.

• **Contractile cells** (Fig. 1.4) are comprised of the following:

1. **The contractile system** made up of myofibers in which the contractile unit is the sarcomere (Figs 1.4A, 1.4B2, and 1.4B3), a structure that can contract and relax. The energy for this activity is provided by mitochondria.

2. **The cellular activation–relaxation system** consisting of the cellular membrane formed by a lipid bilayer (sarcolemma) (Figs 1.4B1 and 1.4B2). Ions (Na^+ , K^+ , and especially Ca^{++}), responsible for activation, depolarization and repolarization, systole, and cellular rest (diastole) phases, flow through channels that exist in this membrane.

3. The transverse tubular (T) system (Fig. 1.4B2), which allows electrical excitation to enter the cell, and the sarcoplasmic reticulum (Fig. 1.4

B2) which contains the calcium necessary for cellular contraction.

4. **The specific cells**, non-contractile, are of three types: (a) **P cells**, the ones with more automaticity, located especially in sinus node 4; (b) **Purkinje cells**, with less automaticity, located especially in the His bundle, bundle branches and Purkinje network; and (c) **transitional cells**.

1.5. The electrophysiology of cardiac cells

1.5.1. Transmembrane diastolic potential (TDP) and transmembrane action potential (TAP) in automatic and contractile cells

All contractile cardiac cells at rest show equilibrium between the external electrical charges and the internal negative charges (Fig. 1.5A). When a micro-electrode is located inside a contractile cell at rest while a second micro-electrode remains in

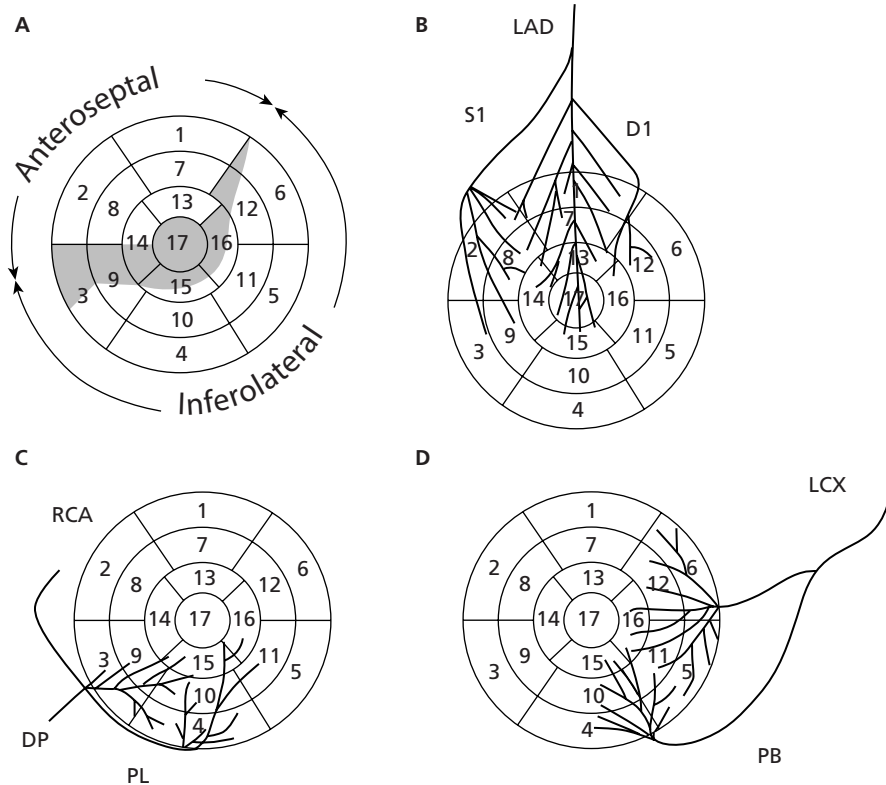


Figure 1.2 According to the anatomical variants of coronary circulation, the areas of shared variable perfusion are shown in grey (A). The perfusion of these segments by the corresponding coronary arteries (B–D) can be seen in the ‘bull’s-eye’ images. For example, the apex (segment 17) is usually perfused by the LAD but sometimes by the RCA, or even the LCX. Segments 3 and 9 are shared by LAD and RCA, and also the small part of the mid-low lateral wall is shared by LAD and LCX. Segments 4, 10 and 15 correspond to the RCA or the LCX, depending on which of them is dominant (the RCA in >80% of the cases). Segment 15 often receives blood from LAD.

the exterior (Fig. 1.5B), a difference in transmembrane potential, called the transmembrane diastolic potential (TDP), is produced. Under normal conditions the voltage is -90mV (Fig. 1.5B).

As contractile cells are not automatic; TDP is rectilinear (Fig. 1.6). This means that during the diastolic phase, an equilibrium between the potassium outward ionic current, and the sodium and calcium inward ionic current takes place.

When the contractile cell receives a stimulus transmitted from a neighboring cell, sodium current enters the cell rapidly. This creates a stimulus upon reaching the threshold potential, which forms the transmembrane action potential (TAP) (Fig. 1.6).

Thus, in the contractile cells the formation of TAP (Fig. 1.6), which is the basis of cellular activation (depolarization and repolarization), takes place because a stimulus (a) transmitted from a neighboring cell, originating from a rapid entry of sodium, reaches the threshold potential (TP) and results in a TAP (b and c are stimuli under threshold potential) (Fig. 1.8B). The TAP has four phases: phase 0 that is the depolarization, the loss of external electrical charges, and phases 1 to 3 involve repolarization, the recovery of these charges.

Cells of the specific conduction system (SCS) have an ascending TDP, because they present some diastolic depolarization due to a rapid

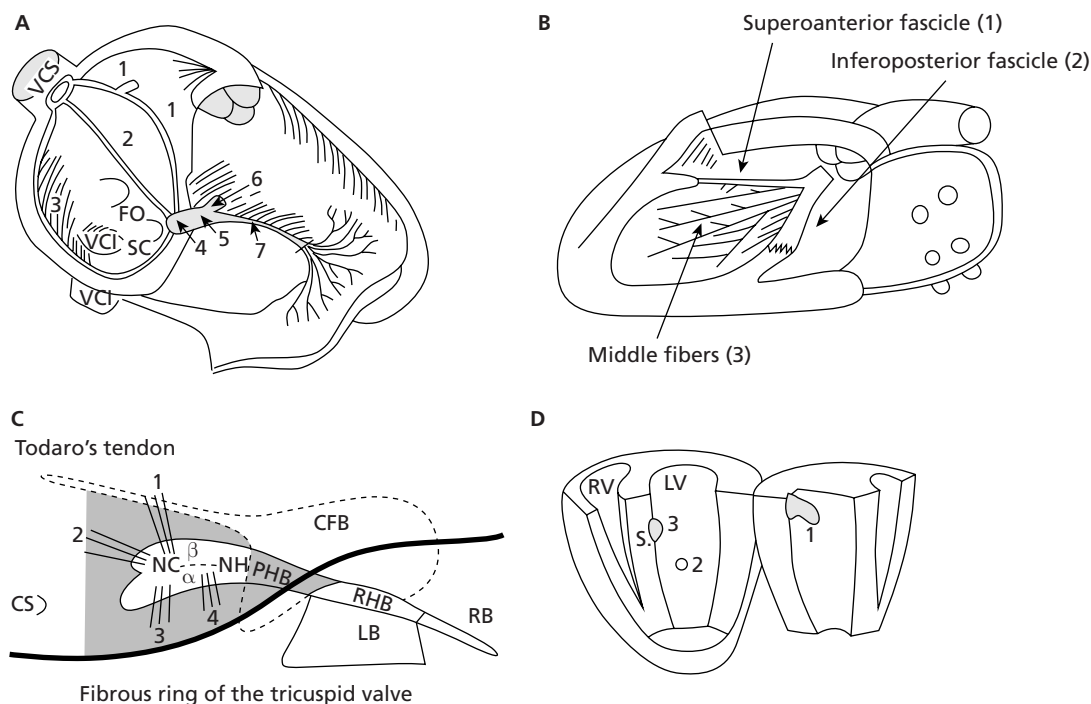


Figure 1.3 (A) Right lateral view of the specific conduction system. 1, 2 and 3: internodal tracts; 4: AV node; 5: bundle of His; 6: left branch; 7: right branch with its ramifications; Ao: aorta; AVN: AV node; CS: coronary sinus; FO: fossa ovalis; IVC: inferior cava vein; SN: sinus node; SVC: superior cava vein. (B) Left lateral view of LV: see the superoanterior (SA) division (1), the inferoposterior (IP) division (2) and the middle fibers (3) (quadrifascicular theory) or rather a quadruple input of ventricular activation theory. (C) Structure of the AV junction extending further than the AV node (the compact node). The zone shaded in gray is included in the AV junction, and may be involved in the reentry circuits exclusive to the AV junction: CFB: central fibrous body; N: compact AV node; PHB: bundle of His—penetrating portion; RHB: bundle of His—ramifying portion; LB: left branch; RB: right branch. Slow conduction (α) and rapid conduction (β) pathways; 1–4: entry of fibers of internodal pathways into the AV node; NH: nodal-His transition zone; CS: coronary sinus. (D) The open left ventricle shows the three points of LV activation according to Durrer (see text).

inactivation of the potassium outward currents. The sinus node (SN) is the SCS structure with the greatest ascending TDP, and thus it presents the greatest automaticity, and is the physiological pacemaker of the heart.

The TAP in automatic cells (Fig. 1.7) takes place when the TDP reaches the threshold potential. This occurs at the exact point when the ionic curves of sodium (arising) and potassium (decreasing) cross (Fig. 1.8), resulting in the entry of sodium into the cell. This occurs more rapidly when the TDP curve is sharper, as in SN automatic cells.

SCS cells after cellular depolarization (TAP) that present slow ascent (phase 0) (contractile cells) experience shorter repolarization phases (2 and 3).

1.5.2. Electroionic correlation in TAP formation (Figs 1.8 and 1.9)

In both contractile (Fig. 1.6) and automatic cells (Fig. 1.7) TAP curves originate because first a rapid entry of sodium occurs, followed by sodium and calcium, into the cell during phase 0, or cellular depolarization. Later this is followed by a slow exit of potassium, resulting in the repolarization process

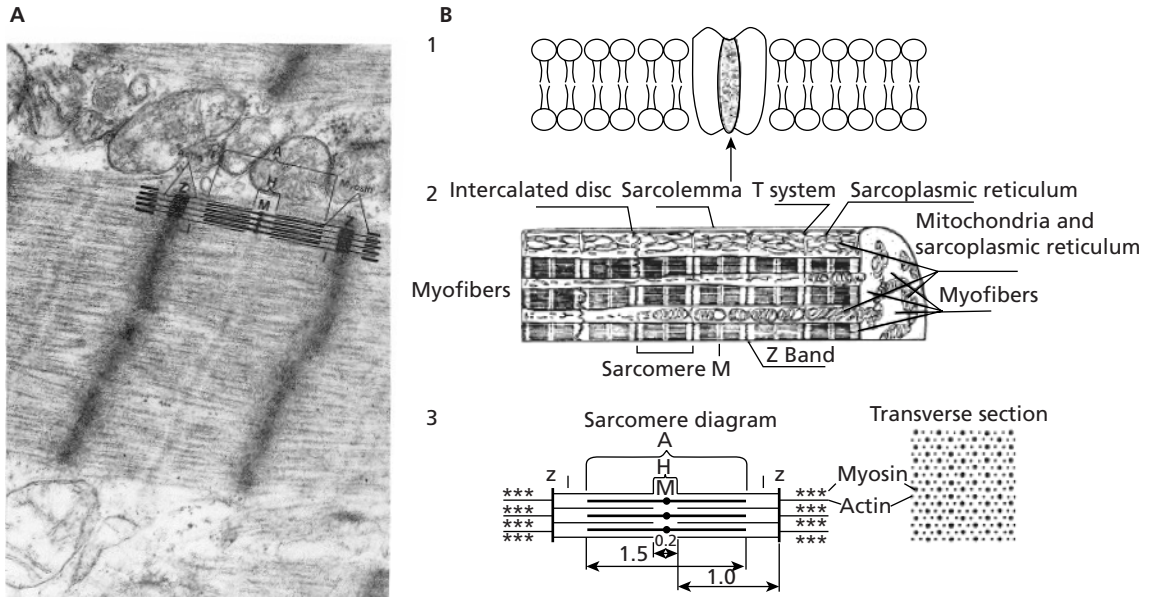


Figure 1.4 (A) Microphotography of a sarcomere where actin and myosin filaments are observed (see B-3). (B-1) Structure of the cellular membrane (or sarcolemma) showing an ionic channel. (B-2) Section of a myocardial contractile cell including all different elements. (B-3) Enlarged sarcomere scheme.

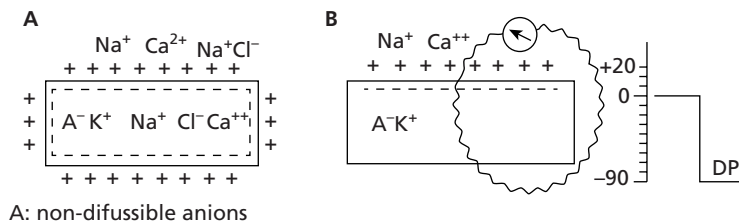


Figure 1.5 (A) The predominant negative charges inside the cell are due to the presence of significant non-diffusible anions which outweigh the ions with a positive charge, especially K^+ . (B) Two microelectrodes placed at the surface of a myocardial fiber record a horizontal reference line during the resting phase (zero line), signifying no potential differences on the cellular surface. When one of the two electrodes is introduced inside the cell, the reference line shifts downwards (-90mV). This line (the DP) is stable in contractile cells and has a more or less ascending slope in the specific conduction system cells (Figs 1.6 and 1.7).

(phases 2 and 3). Figure 1.8 shows this process in a contractile cell through the formation of the depolarization and repolarization dipoles, which will be explained in the next chapter (Bayés de Luna, 2012a). Figure 1.9 shows the most relevant ionic current in automatic (A), and contractile cells (B) during systole.

1.5.3. Stimuli transmission from the sinus node to the contractile myocardium

Figure 1.10 shows how stimuli are transmitted from the SN (the most automatic cells) to the AV node, branches and ventricular Purkinje fibers, which present progressively less automatism, and

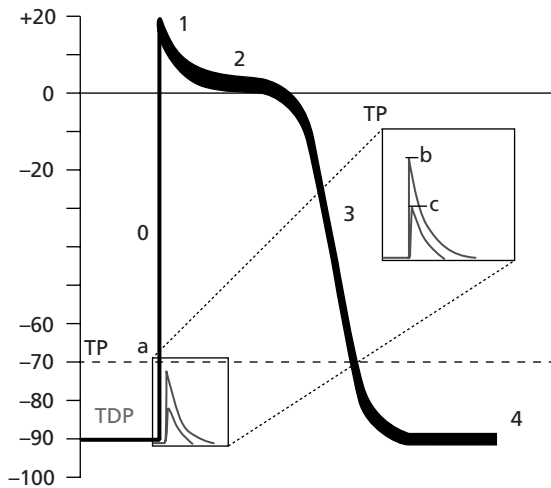


Figure 1.6 Transmembrane diastolic or resting potential (TDP) and transmembrane action potential (TAP) of contractile cells.

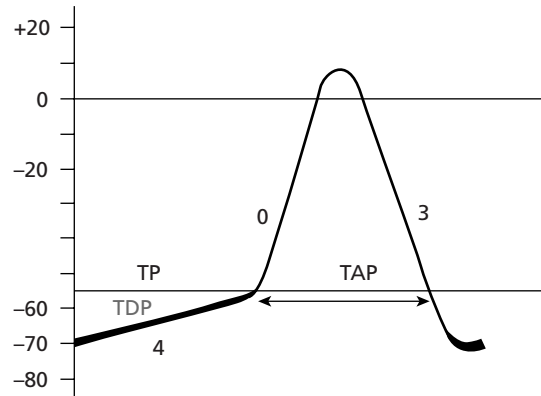


Figure 1.7 Transmembrane diastolic or resting potential (TDP) and transmembrane action potential (TAP) of automatic cells.

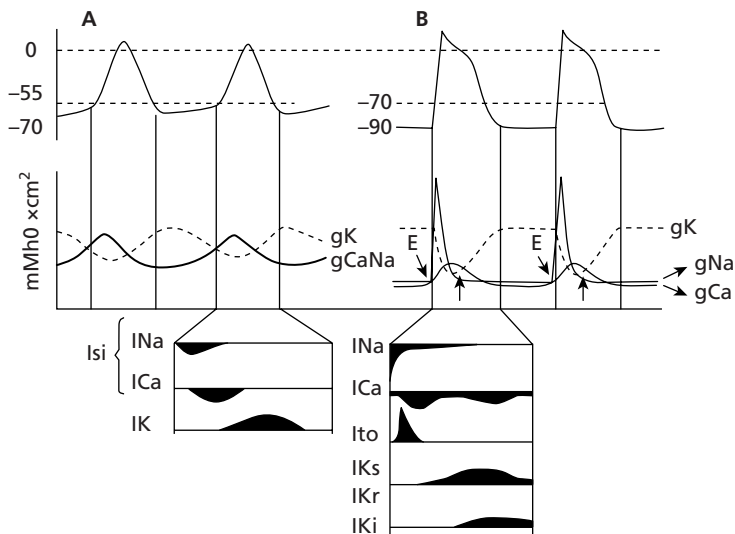


Figure 1.8 The most relevant ionic currents in automatic (A) and contractile (B) cells during systole. Contractile cells are characterized by an early and abrupt Na^+ inward flow and an initial and transient K^+ outward flow (I_{to}). These are not present in automatic cells.

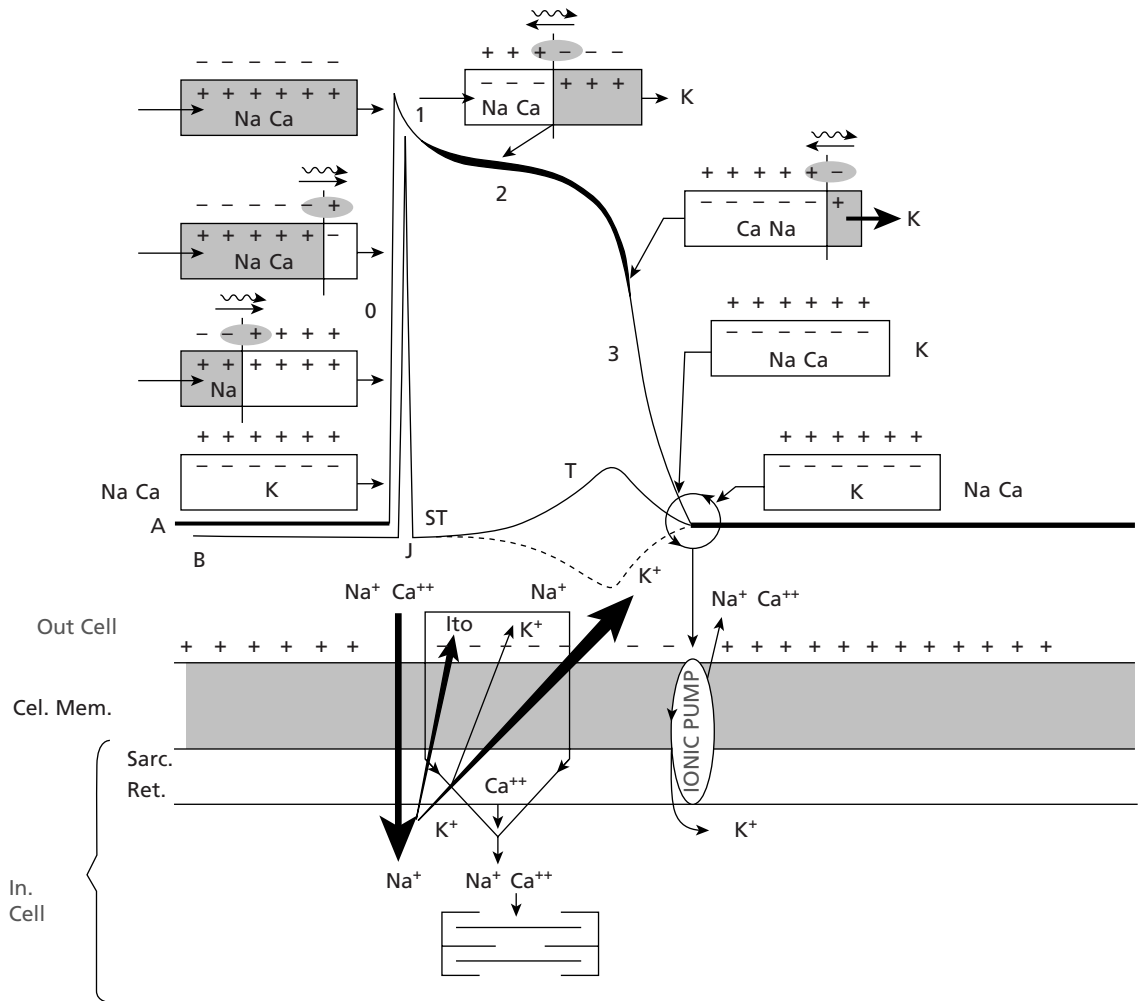


Figure 1.9 Diagram of the electro-ionic changes occurring during cellular depolarization and repolarization of contractile myocardium cells. In phase 0, when the Na inward flow occurs, the depolarization dipole (−+) is formed. In phase 2, when an important and constant K outward flow is observed, the repolarization dipole is formed (+−). Depending on whether we examine a single cell or the whole left ventricle, a negative repolarization wave (broken line) or a positive repolarization wave (continuous line) is recorded respectively (see Section 2.1.2 in Chapter 2).

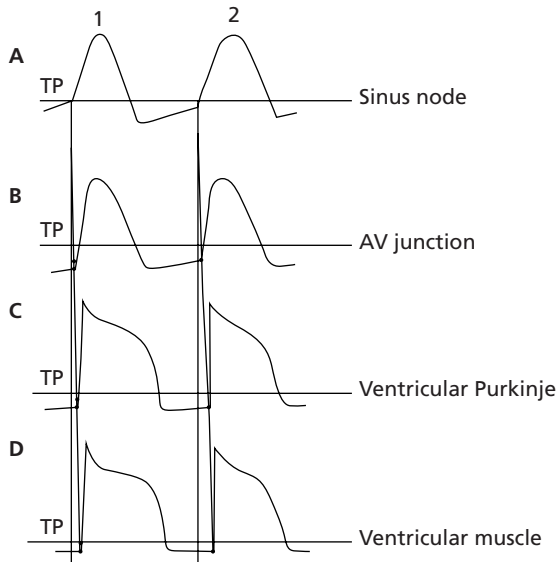


Figure 1.10 Sinus node AP (A) transmitted to the AV junction (B), the ventricular Purkinje (C) and ventricular muscle (D) (TP: threshold potential).

finally to the ventricular muscles (nonautomatic contractile cells). This process is explained in the next chapter in the section on heart activation and the domino theory.

Self-assessment

- A.** Which segment of the LV does the area previously known as the posterior wall correspond to?
- B.** Which artery perfuses the LV apex?
- C.** How many activation entry points are in the LV?
- D.** How many types of cardiac cells exist?
- E.** What is TDP?
- F.** What is TAP?
- G.** What role do ions play in the formation of TAP?