PART I

Electrocardiographic patterns of ischaemia, injury and infarction

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CHAPTER 1

Anatomy of the heart: the importance of imaging techniques correlations

The surface electrocardiography (ECG) in both acute and chronic phase of ischaemic heart disease (IHD) may give crucial information about the coronary artery involved and which is the area of myocardium that is at risk or already infarcted. This information jointly with the ECG–clinical correlation is very important for prognosis and risk stratification, as will be demonstrated in this book. Therefore, we will give in the following pages an overview of the anatomy of the heart, especially the heart walls and coronary tree, and emphasise the best techniques currently used for its study.

For centuries, since the pioneering works of Vesalio, Leonardo da Vinci, Lower and Bourgery-Jacob, pathology has been a unique method to study the anatomy of the heart. Since the end of the nineteenth century, the visualisation of the heart in vivo has been possible by **X-ray examination**. The last 40–50 years started the era of invasive imaging techniques with **cardiac catheterisation** (**angiography and coronary angiography**) and modern non-invasive imaging techniques, first with **echocardiography** and later with **isotopic studies**, **scanner and cardiovascular magnetic resonance** (**CMR**). These techniques open a new avenue to study not only the anatomy of the heart, coronary arteries and great vessels but also the myocardial function and perfusion, and the characterisation of the valves, pericardium, etc.

The coronary angiography (Figure 1.1) is especially important in the acute phase for diagnosing the disease and correlating the place of occlusion with the ST-segment deviations. It is also useful in the chronic phase of the disease. However, in the chronic phase of Q-wave myocardial infarction (MI) the ECG does not usually predict the state of the coronary tree, because the revascularisation treatment has modified, sometimes very much, the characteristics of the occlusion responsible for the MI. Furthermore, the catheterisation technique may give important information for identifying hypokinetic or akinetic areas. The latter may be considered comparable to infarcted areas (Shen, Tribouilloy and Lesbre, 1991; Takatsu et al., 1988; Takatsu, Osugui and Nagaya, 1986; Warner et al., 1986). Currently, in some cases, the non-invasive **coronary multidetector computer tomography** (CMDCT) may be used (Figure 1.1).

The era of modern non-invasive imaging techniques started with **echocardiography**, which is very easy to perform and has a good cost-effective relation. This technique plays an important role, especially in the acute phase, in the detection of left-ventricular function and mechanical complications of acute MI (Figures 1.2, 8.28 and 8.29). Also, it is very much used in chronic ischaemic-heart-disease patients for the study of left-ventricular function and also detection of hypokinetic and akinetic areas (Bogaty et al., 2002; Matetzky et al., 1999; Mitamura et al., 1981). However, echocardiography tends to overestimate the area that is at risk or necrosed, and thus its reliability is good but not excellent. The techniques of echo stress and especially **isotopic studies** (**single-photon emission computed tomography**, **SPECT**) have proved to be very reliable for detecting perfusion defects and necrotic areas (Gallik et al., 1995; Huey et al., 1988; Zafrir et al., 2004) (Figure 1.3). They are very useful in cases where there is dubious precordial pain with positive exercise testing without symptoms (Figure 4.58). It has been demonstrated, however, that in some cases (non-Q-wave infarction) the

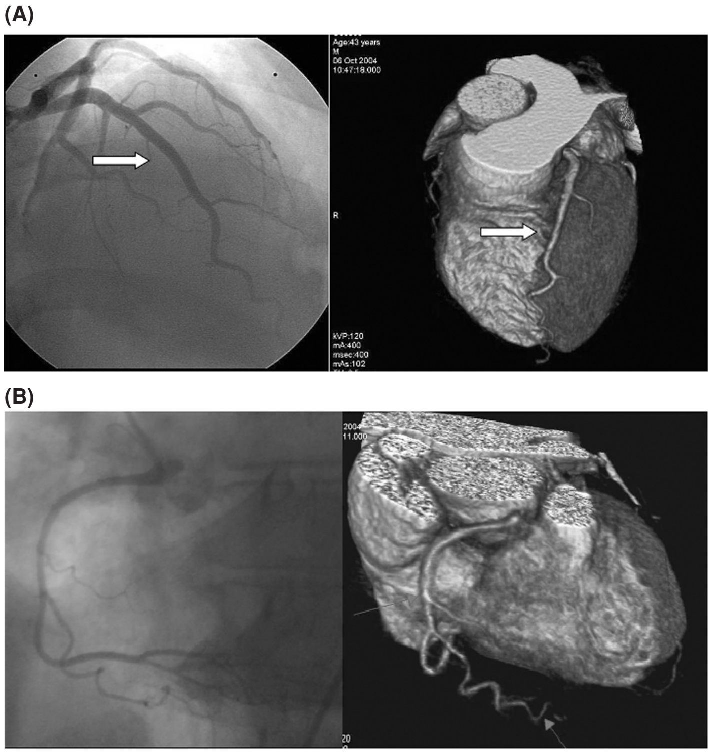
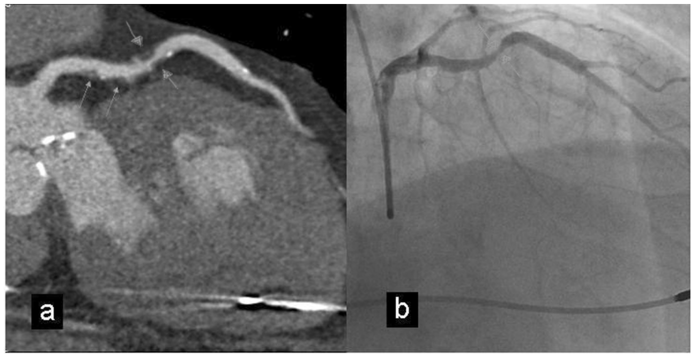


Figure 1.1 (A) Normal case: coronary angiography (left) and three-dimensional volume rendering of CMDCT (right) showing normal LAD and LCX artery. The latter is partially covered by left appendix in CMDCT. The arrow points out LAD. (B) Normal case: coronary arteriography (left) and three-dimensional volume rendering of CMDCT (right) showing normal dominant RCA. (C) 85-year-old man with atypical anginal pain: (a) Maximal intensity projection (MIP) of CMDCT with clear tight mid-LAD stenosis that correlates perfectly with the result of coronary angiography performed before PCI (b). (D) Similar case as (C) but with the stenosis in the first third of RCA ((a–d) CMDCT and (e) coronary arteriography). (E) Similar case as (C) and (D) but with the tight stenosis in the LCX before the bifurcation ((a) and (b) CMDCT and (c) coronary angiography). (F) These images show that CMDCT may also demonstrate the presence of stenosis in distal vessels, in this case posterior descending RCA ((a–b) CMDCT and (c)) coronary angiography). (G) These images show that CMDCT (a, b) may delimitate the length of total occlusion and visualise the distal vessels (see arrows in (b), the yellow ones correspond to distal RCA retrograde flow from LAD) that is not possible to visualise with coronary angiography (c). (H) A 42-year-old man sports coach with a stent implanted in LAD by anginal pain 6 months before. The patient complains of atypical pain and present state of anxiety that advises to perform a CMDCT to assure the good result and permeability of the stent. In the MIP of CMDCT (a–c) was well seen the permeability of the stent but also a narrow, long and soft plaque in left main trunk with a limited lumen of the vessel (see (d) rounded circle) that was not well seen in the coronary angiography (e) but was confirmed by IVUS (f). The ECG presents not very deep negative T wave in V1–V3 along all the follow-up. This figure can be seen in colour, Plate 1.

extension of the infarction may be underestimated and that in presence of the left bundle branch block (LBBB) the estimation of some perfusion defects is doubtful.

The most recent imaging techniques are **CMR** (Figure 1.4) and **CMDCT** (Figure 1.1). The latter is used for non-invasive study of coronary tree. CMR, which may also be used for perfusion and function studies of the myocardium, gives us the best ‘in vivo’ anatomic information about the heart. Thus, this technique, in conjunction with gadolinium injection and contrast-enhanced CMR (CE-CMR), is very useful for identifying and locating MI, as well as for determining its transmurality with extraordinary reliability, comparable to pathological studies (Bayés de Luna et al., 2006a–c; Cino et al.,

(C)



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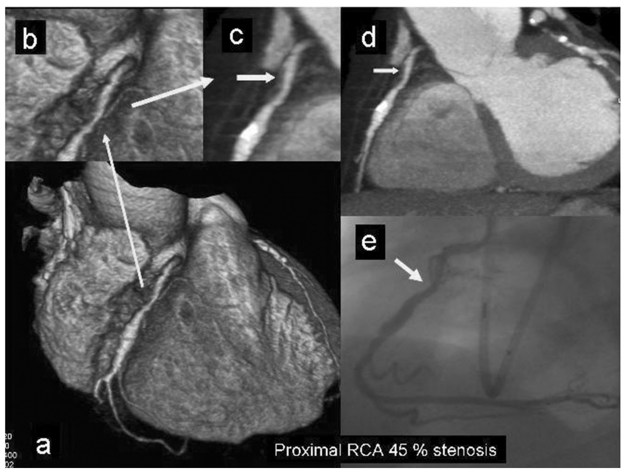


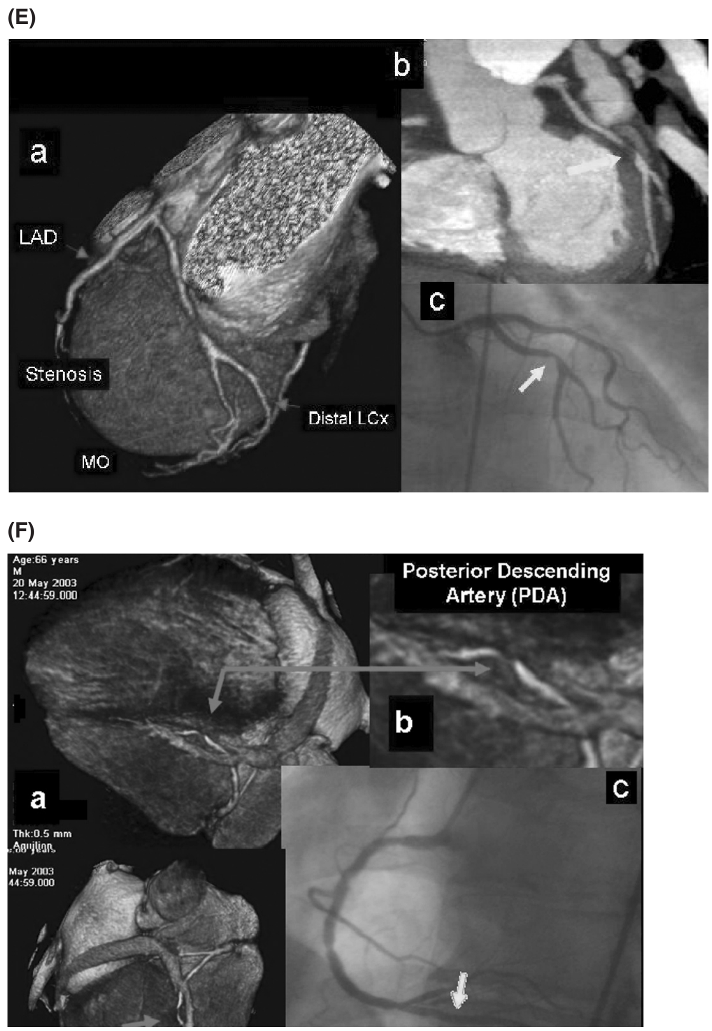
Figure 1.1 (*Continued*)

2006; Moon et al., 2004; Salvanayegam, 2004; Wu et al., 2001). This is why CE-CMR has become the gold-standard technique for studying correlations between ECG findings and infarcted myocardial areas in the chronic phase of IHD (Bayés de Luna et al., 2006a–c; Cino et al., 2006; Engblom et al., 2002, 2003). Also, CE-CMR may distinguish according to location the hyperenhancement areas between ischaemic and non-ischaemic patients (Figure 1.5) and may show in vivo the sequence of the evolving transmural MI (Mahrholdt et al., 2005a, b) (Figure 8.5). The reproducibility of CE-CMR along time, especially after the acute phase, is very good. It also has the advantage of not producing radiation. The current limitation of CMR, which will probably be solved in the next few years, is the study of coronary tree. Currently, this may be performed non-invasively by CMDCT (see above Fig 1.1).

The heart walls and their segmentation: cardiac magnetic resonance (Figures 1.4–1.14)

The heart is located in the central-left part of the thorax (lying on the diaphragm) and is oriented anteriorly, with the apex directed forwards, and from right to left (Figure 1.4).

The left ventricle (LV) is cone shaped. Although its borders are imprecise, classically (Myers et al., 1948a, b; Myers, Howard and Stofer, 1948), it has been divided, except in its inferomost part the apex, into four walls, till very recently named septal, anterior, lateral and inferoposterior. In the 1940s–1950s the inferoposterior wall was named just posterior (Goldberger, 1953) (Figure 1.6A), probably because it was considered opposed to the anterior wall. Later on (Perloff, 1964), only the basal part of this wall, which was thought to bend upwards, was considered really a posterior wall (Figure 1.6B). Therefore,



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it was named 'true posterior' and the rest of the wall just 'inferior wall' (Figure 1.6). According to that, for more than 40 years the terms 'true' or 'strict posterior infarction', 'injury' and 'ischaemia' have been applied, when it was considered that the basal part of the inferoposterior wall was affected. The committee of the experts of the International Society of Computerised ECG (McFarlane and Veitch Lawrie, 1989), in accordance with the publications of Selvester and Wagner, has named these walls anterosuperior, anterolateral, posterolateral and inferior, respectively. However, this nomenclature has not been popularised, and the classical names (Figure 1.7A) are still mostly used in the majority of papers (Roberts and Gardin, 1978), ECG books (Figure 1.7B to D), task force (Surawicz et al., 1978) and statements (Hazinsky, Cummis and Field, 2000).

Later on, in the era of imaging techniques, the heart was transected into different planes (Figure 1.7) and different names were given to the heart walls by echocardiographists and experts in nuclear medicine. However, recently, the consensus of the North American Societies for Imaging (Cerqueira, Weissman and Disizian, 2002) divided the LV in 17 segments and **4 walls**: **septal**, **anterior**, **lateral** and **inferior** (Figures 1.8 and 1.9). This consensus states that the classical inferoposterior wall should

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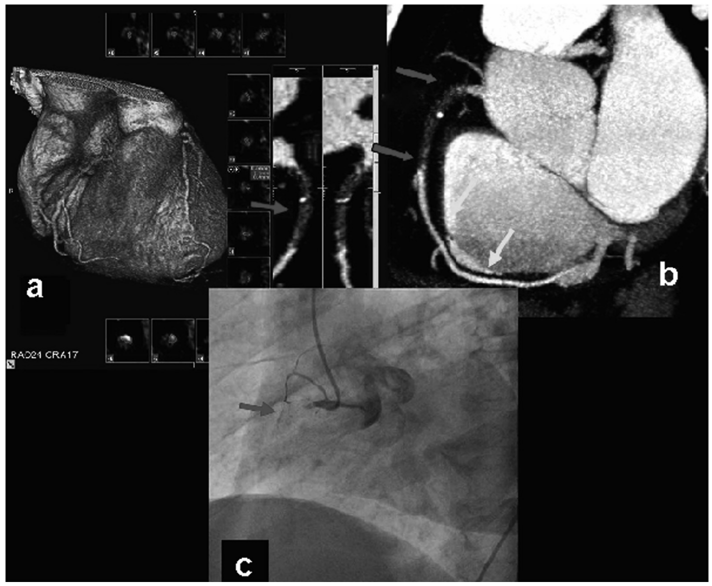

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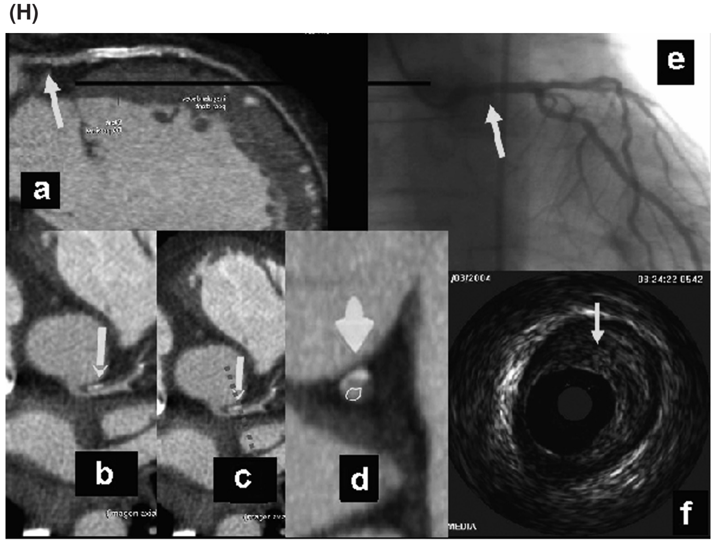

Figure 1.1 (*Continued*)

be called inferior 'for consistency', and segment 4 should be called inferobasal instead of posterior wall. Therefore the word 'posterior' has to be suppressed. Figures 1.8 and 1.9 show the 17 segments into which the four left-ventricular walls are divided (6 basal, 6 medial, 4 inferior and the apex), and the right side of Figure 1.9 shows the heart walls with their corresponding segments on a polar 'bull's-eye' map, as used by specialists in nuclear medicine. Now we will explain, thanks to correlations with CMR, why we consider that this terminology (Cerqueira, Weissman and Disizian, 2002) is the best and it will be used further in this book. Page 16 shows the evolution of the terminology given to the wall that lies on the diaphragm.

If we consider that the heart is located in the thorax in a strictly posteroanterior position, as is presented by anatomists and by experts in nuclear

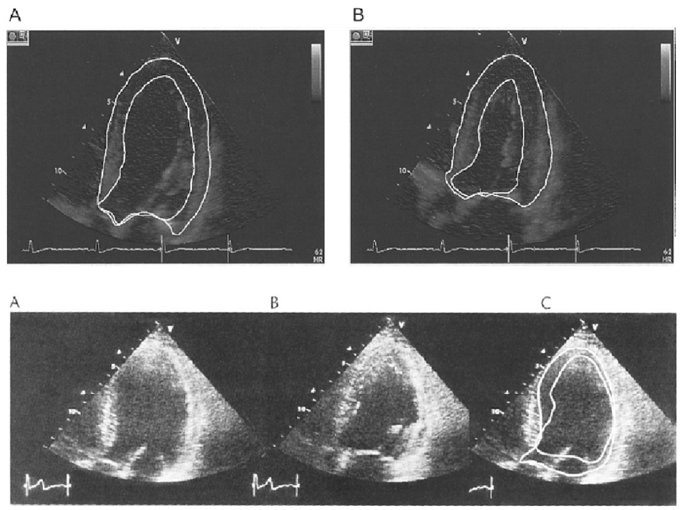

Figure 1.2 Echocardiography: see example of volumes, wall thickening and myocardium mass in a normal case and in a patient with post-MI. Above: (A) End-diastolic and (B) end-systolic apical long-axis views of a normal left ventricle. The endocardial and epicardial contours are traced and the built-in computer software of the ultrasound system allows calculation of volumes, wall thickening and myocardial mass. Below: Segmental wall function analysis: post-infarct lateral wall hypokinesis shown in the four view. The left ventricle is dilated. Superposition of the traced endocardial contours at end diastole (A) and end systole (B) shows the hypokinesis and compensatory hyperkinesis of the interventricular septum. (C) It shows the superimposed end-diastolic and end-systolic contours. (Adapted from Camm AJ, Lüscher TF and Serruys PW, 2006.)

medicine, and in the transverse section of CMR images (Figure 1.10A–C), we may understand that in case of involvement (injury or infarction) of basal part of inferior wall (classically called posterior wall) especially when in lean individuals the majority of inferior wall is placed in a posterior position (Figure 1.13C), an RS (R) and/or ST-segment depression in V1 will be recorded (Figure 1.10D). However, now, thanks to magnetic resonance correlations (Figure 1.11), we have evidence that the sagittal view of the heart is, in respect to the thorax, located with an oblique right-to-left inclination and not in a strictly posteroanterior position, as was usually presented by anatomists, nuclear medicine and the transverse section of CMR (Figure 1.10). This helps us to understand how the RS (R) or predominant ST-segment depression patterns in V1 is the consequence of the infarction of or injury to the lateral, not the inferobasal, segment (classical posterior wall) (Figure 1.12). However, we have to remind

The usefulness of invasive and non-invasive imaging techniques and their correlations with ECG in IHD:

- Non-invasive imaging techniques, especially SPECT, are very useful in detecting perfusion defects during exercise test.
- We will present in this book the importance of ECG–coronary angiography correlations to identify the artery occlusion site and the myocardial area at risk.
- The role of coronary angiography, and in special circumstances, of non-invasive detection of coronary tree by CMDCT in chronic-heart-disease patients, will be commented.
- In chronic Q-wave MI we will emphasise the importance of the ECG–CMR correlations to identify and locate the area of infarction.
- ECG is very useful in coronary care unit and is also used routinely in the chronic phase.
- X-ray examination still plays some role especially in the acute phase (heart enlargement and pulmonary oedema) and in the detection of aneurysms and calcifications, visualisation of heart valves, pacemakers, etc.

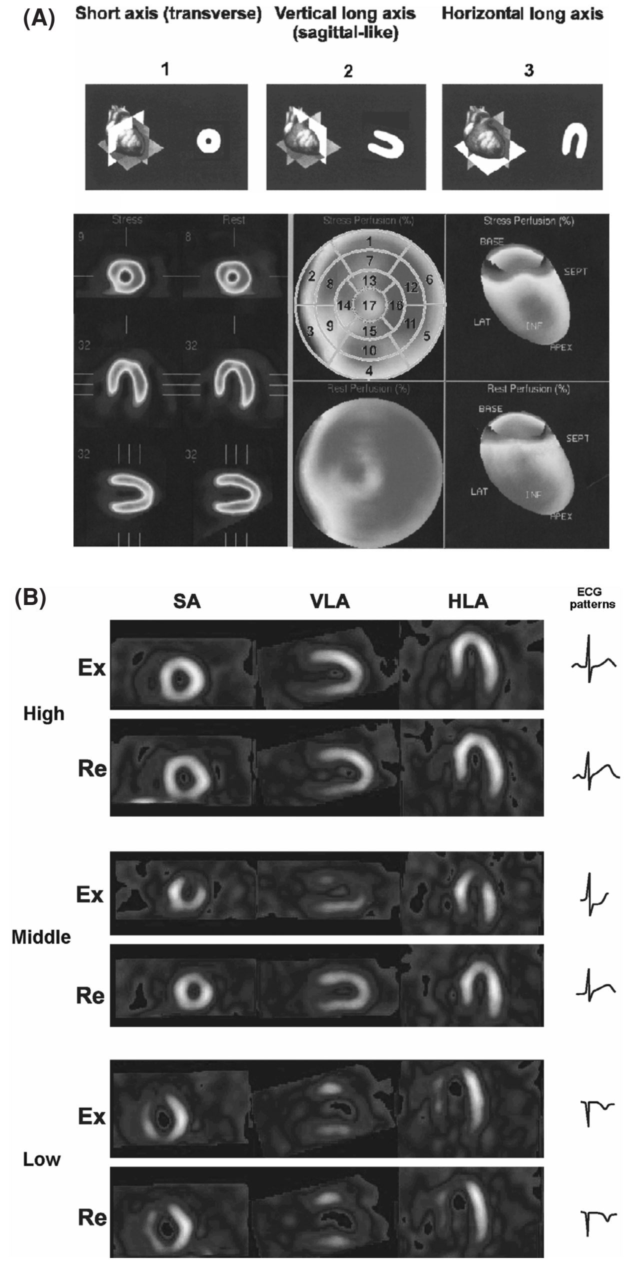

Figure 1.3 Examples of correlation exercise test – isotopic images (SPECT). (A) Above: Observe the three heart planes (see Figure 1.4B) used by nuclear medicine experts (and other imaging techniques) to transect the heart: (1) short-axis (transverse) view (SA), (2) vertical long-axis view (VLA) (oblique sagittal-like) and (3) horizontal long-axis (HLA) view. Below: Normal case of perfusion of left ventricle. On the middle is (B) the bull's-eye image of this case. The segmentation of the heart used in this book is shown (Cerqueira, Weissman and Disizian, 2002). On (A) transections of the three axes are shown. The short-axis transections is at the mid-apical level (see Figure 1.8 for segmentation). (B) Above: In the three planes (SA, VLA and HLA) see (A) normal uptake at rest (Re) and during exercise (Ex) can be observed. Middle: Abnormal uptake only during exercise of segments 7, 13 and 17 (see Figure 1.8) in a patient with angina produced by distal involvement of not long LAD. The basal part of the anterior wall of left ventricle is not involved. Below: Abnormal uptake during rest and exercise in a patient in chronic phase of MI produced by distal occlusion of very long LAD that wraps the apex involving part of inferior wall (segments 7, 13 and 17 and also 15) (see Figure 1.8), without residual ischaemia on exercise. In this case the image of abnormal uptake is persistent during rest. See in all cases the ECG patterns that may be found. This figure can be seen in colour, Plate 2.

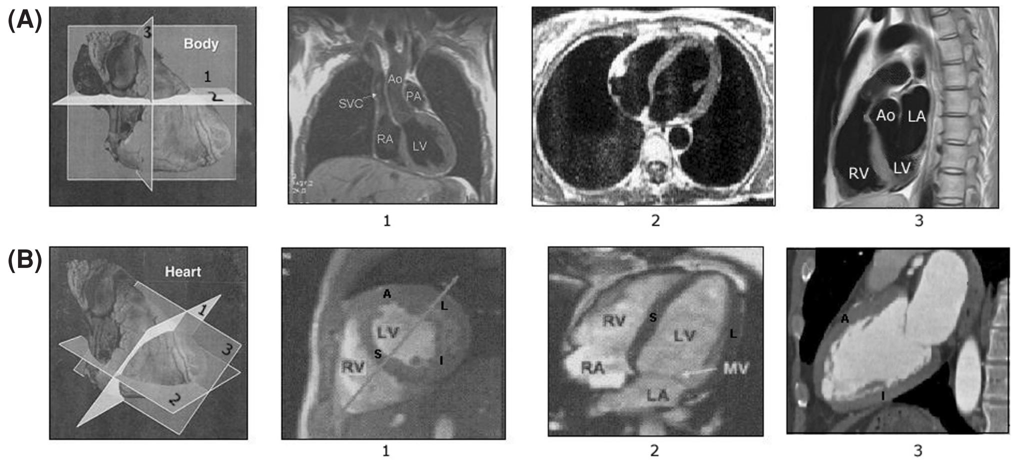

Figure 1.4 Cardiac magnetic resonance imaging (CMR). (A) Transections of the heart following the classical human body planes: (1) frontal plane, (2) horizontal plane and (3) sagittal plane. (B) Transections of the heart following the heart planes that cut the body obliquely. These are the planes used by the cardiac imaging experts: (1) short-axis (transverse) view, in this case at mid-level (see B(1)); (2) horizontal long-axis view; (3) vertical long-axis view (oblique sagittal-like). Check the great difference between the sagittal plane according to human body planes (A(3)) and the heart planes (B(3). (B) It shows the four walls of the heart with the classical names: septal (S), anterior (A), lateral (L) and inferoposterior. Currently, the inferoposterior wall is named for consistency just inferior (I) (see p. 16 and Figure 1.8).

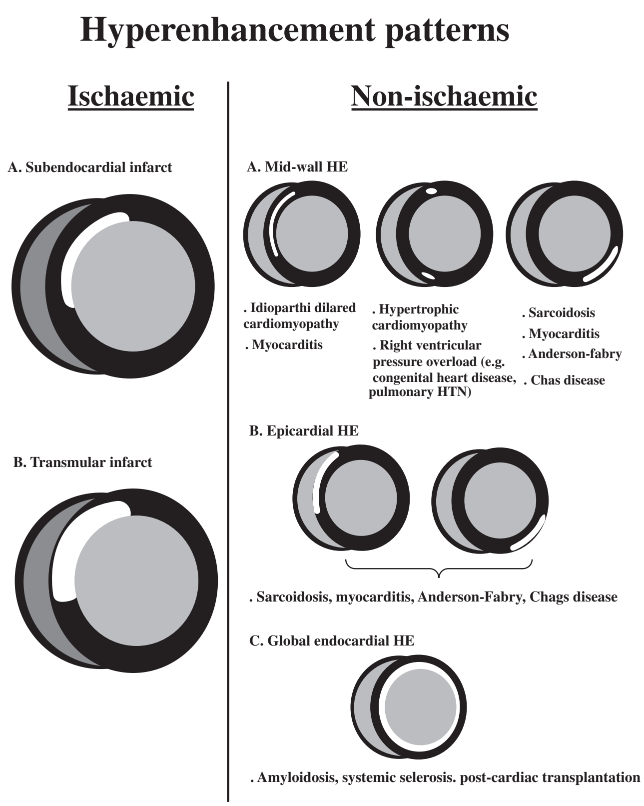

Figure 1.5 Hyperenhancement patterns found in clinical practice. If hyperenhancement is present, the subendocardium should be involved in patients with ischaemic disease. Isolated mid-wall or subepicardial hyperenhancement strongly suggests a 'non-ischaemic' etiology. (Taken from Marhrholdt, 2005.)

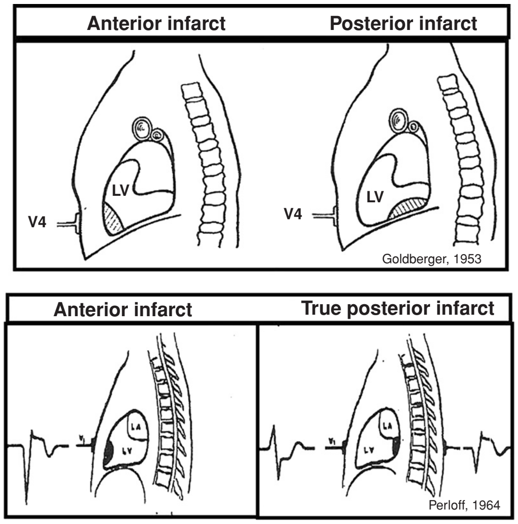

Figure 1.6 Above: The concept of anterior and posterior infarction according to Goldberger (1953). Below: The concept of anterior and true or strict posterior infarction is shown according to Perloff (1964). The other part of the wall that lies on the diaphragm became to be named inferior (see p. 16).

that in the majority of cases except for very lean individuals (see Figure 1.13C), the part of the inferior wall that is really posterior just involves the area of late depolarisation (segment 4, or inferobasal). Therefore, in case of MI of this area, there would not be changes in the first part of QRS, because this MI does not originate a Q wave or an equivalent wave (Durrer et al., 1970).

The CMR technique gives us real information about the in vivo heart's anatomy (Blackwell, Cranney and Pohost, 1993; Pons-Lladó and Carreras, 2005) (Figure 1.4). In this regard, the following are important:

(**a**) CMR patterns of the frontal, horizontal and sagittal planes of the heart following the human body planes are shown in Figure 1.4A. This allows us to know with precision the heart's location within the thorax. In this figure we can observe these transections, performed at the mid-level of the heart.

(**b**) Nevertheless, bearing in mind the three-dimensional location of the heart within the thorax, in order to correlate the left ventricular walls amongst themselves and, above all, to locate the different segments into which they can be divided, it is best to perform transections following the heart planes that are perpendicular to each other (see Figure 1.4B), as has been already done in nuclear medicine (Figure 1.3; see Plate 2). These planes transect the heart following the heart planes (Figure 1.4B) and are the following: horizontal long-axis view, short-axis view (transverse) and vertical long-axis view (oblique sagittal-like). In reality the oblique sagittal-like view (Figure 1.11B) presents, as we have said, an oblique right to left and not a strict posteroanterior direction (compare Figure 1.4A(3) with Figures 1.4B(3) and 1.11B). Therefore in the presence of infarction of the inferobasal part of inferior wall (classically called posterior wall) and especially when the infarction involves the mid-inferior wall if it is located posteriorly, as happens in very lean individuals (Figure 1.13C), the vector of infarction generated in this area is directed forwards and from right to left and is recorded as RS morphology in V2–V3, but not in V1 where it presents a normal rS morphology (Figure 1.12B). On the contrary, the vector of infarction, in the case of infarction involving the lateral wall, may generate an RS pattern in V1 (Bayés de Luna, Batchvarov and Malik, 2006; Bayés de Luna, Fiol and Antman, 2006; Cino et al., 2006) (Figure 1.12C) (see legend Figure 1.12).

(**c**) The longitudinal vertical plane (Figures 1.3(2), 1.8C and 1.11B; see Plate 2) is not fully sagittal with respect to the anteroposterior position of the thorax, but rather oblique sagittal, as it is directed from right to left. (The sagittal-like axis follows the CD line in Figure 1.11A.) Compare Figures 1.4B(3) and 1.11B with the true sagittal view – Figure 1.4A(3). The view of this plane, as seen from the left side (oblique sagittal), allows us to correctly visualise the anterior and the inferior heart walls (Figure 1.11B). We can clearly see that the inferior wall has a portion that lies on the diaphragm until, at a certain point, sometimes it changes its direction and becomes posterior (classic posterior wall), now called inferobasal segment. This posterior part is more or less important, depending on, among other factors, the body-build. We have found (Figure 1.13) that in most cases the inferior wall remains flat (C shape) (Figure 1.13B). However, sometimes a clear basal part bending upwards (G shape) (Figure 1.13A) is seen. Only rarely, usually in very lean individuals, does the great part of the inferior wall present a clear posterior position (U shape) (Figure 1.13C).

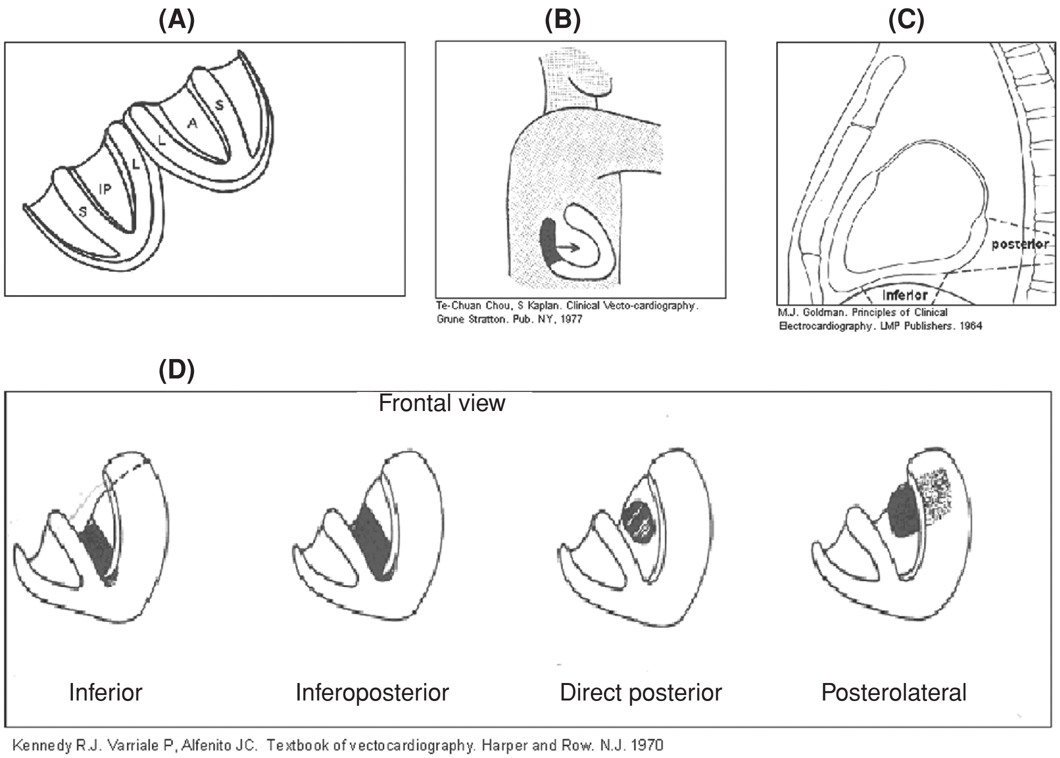

Figure 1.7 (A) The left ventricle may be divided into four walls that till very recently were usually named anterior (A), inferoposterior (IP) or diaphragmatic, septal (S) and lateral (L). However, according to the arguments given in this book, we consider that the 'inferoposterior' wall has to be named just 'inferior' (see p. 16). (B–D) Different drawings of the inferoposterior wall (inferior + posterior walls) according to different ECG textbooks (see inside the figure). In all of them the posterior wall corresponds to the basal part of the wall lying on the diaphragm that was thought to bend upwards. It was considered that the heart was located strictly in a posteroanterior position in the thorax (Figures 1.10D and 1.12A). The cardiovascular magnetic resonance (CMR) gives us the information that the inferoposterior wall lies flat, even in its basal part, in around two-third of cases (Figure 1.13) and make evident that the heart is always placed in an oblique position (Figure 1.12B,C).

Therefore, often, the posterior wall does not exist and for this reason, the name 'inferior wall' seems clearly better than the name 'inferoposterior'. On the other hand, the anterior wall is, in fact, superoanterior, as is clearly appreciated in Figure 1.11B. However, in order to harmonise the terminology with imaging experts and to avoid more confusion, we consider that the names 'anterior wall' and 'inferior wall' are the most adequate for its simplification and also, because when an infarct exists in the anterior wall, the ECG repercussion is in the horizontal plane (HP; V1–V6) and when it is in the inferior wall – even in the inferobasal segment – it is in the frontal plane (FP).

(d) The longitudinal HP (Figures 1.3(3) and 1.8B; see Plate 2) is directed from backwards to forwards from rightwards to leftwards, and slightly cephalocaudally. In Figure 1.8A (arrows), one can appreciate how, following the line AB, the heart can be opened like a book (Figure 1.8B).

(e) The transverse plane (Figures 1.4B(1), 1.3A(1) and 1.8A), with respect to the thorax, is directed predominantly cephalocaudally and from right to left, and it crosses the heart, depending on the transection performed, at the basal level, mid-level or apical level (Figure 1.8A). Thanks to these transverse transections performed at different levels, we are able to view the right ventricle (RV) and the left-ventricular

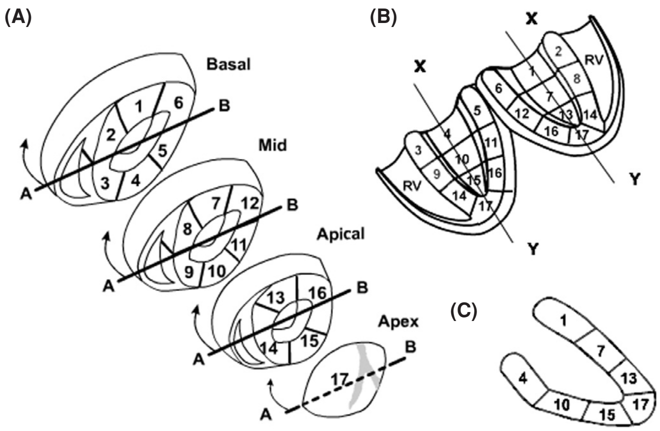

Figure 1.8 (A) Segments into which the heart is divided, according to the transverse (short-axis view) transections performed at the basal, mid and apical levels. The basal and medial transections delineate six segments each, while the apical transection shows four segments. Together with the apex, they constitute the 17 segments in which the heart can be divided according to the classification performed by the American imaging societies (Cerqueira, Weissman and Disizian, 2002). (B) View of the 17 segments with the heart open in a horizontal long-axis view and (C) vertical long-axis (sagittal-like) view seen from the right side. Figure 1.14 shows the perfusion of these segments by the corresponding coronary arteries.

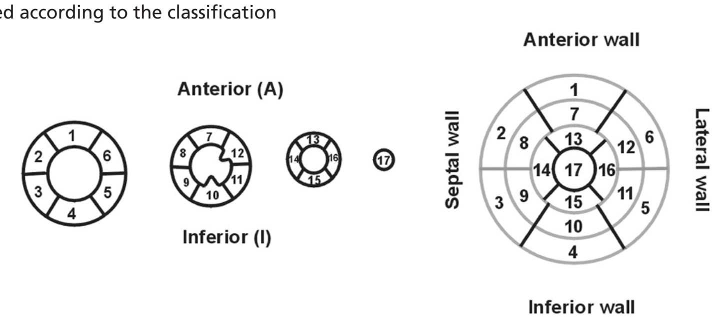

Figure 1.9 Images of the segments into which the left ventricle (LV) is divided according to the transverse transections (short-axis view) performed at the basal, mid and apical levels, considering that the heart is located in the thorax just in a posteroanterior and right-to-left position. Segment 4, inferobasal, was classically named posterior wall. The basal and medial transections delineate six segments each, while the apical transection shows four segments. Together with the apex, the left ventricle can be divided into 17 segments. Note, in the mid-transection, the situation of the papillary muscles is shown. To the right, all 17 segments in the form of a polar map (bull's-eye), just as it is represented in nuclear medicine reports.

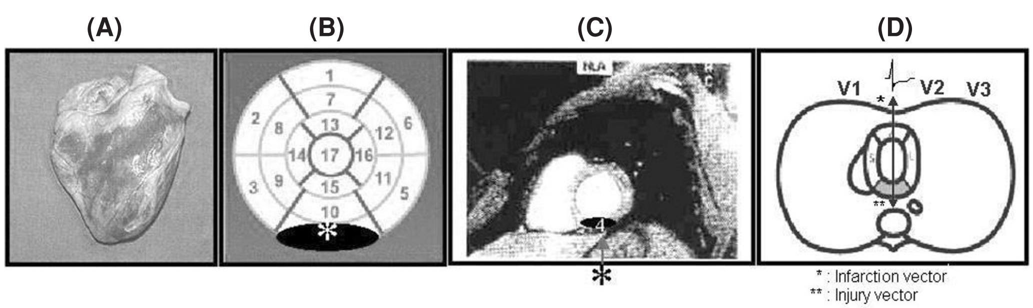

Figure 1.10 (A) The heart, shown out of the thorax by anatomists and pathologists; (B) bull's-eye image as it is shown by nuclear medicine and (C) transverse transection as it is shown by CMR. In both cases the position of the heart is presented as if the heart was located in the thorax in a strictly posteroanterior position. (D) The injury and infarction vectors (Inj. V and Inf. V) with the same direction but different sense may be seen. Compare the differences in the transections of the heart presented in Figure 1.4(above) taking the body as a centre and 1.4(below) taking the heart as a center.

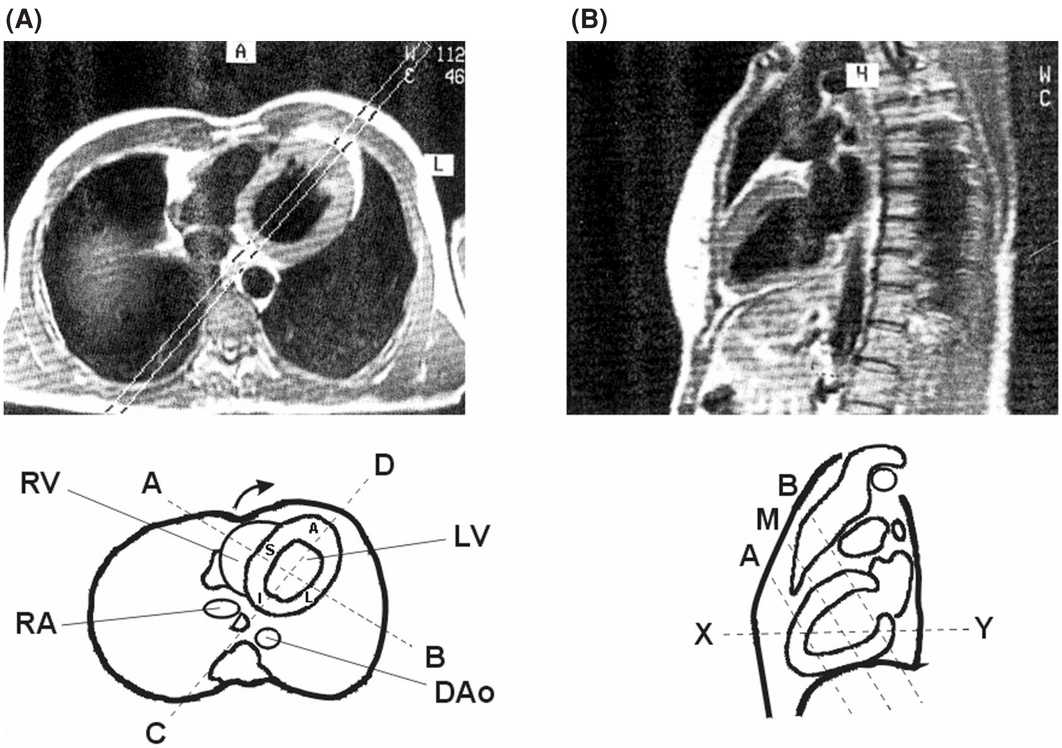

Figure 1.11 Magnetic resonance imaging. (A) Thoracic horizontal axial plane at the level of the '*xy*' line of the drawing on the right side of the figure. The four walls can be adequately observed: anterior (A), septal (S), lateral (L) and inferior (I), represented by the inferobasal portion of the wall (segment 4 of Cerqueira statement) that bends upwards in this case (B). The infarction vector generated principally in segments 4 and 10; in case of very lean individuals (Figure 1.13C) it faces lead V3 and not V1 (line CD). On the contrary, the vector of infarction that arises from segments 5 and 11 (lateral wall) faces V1 and therefore explains RS morphology in this lead (line BA). (B) According to the transection, following the vertical longitudinal axis of the heart (line CD in (A)), we obtain a sagittal oblique view of the heart from the left side. These four walls, anterior, inferior (inferobasal), septal and lateral, are clearly seen in the horizontal axial plane (A), and two walls, anterior and inferior including the inferobasal segment, in sagittal-like plane (B).

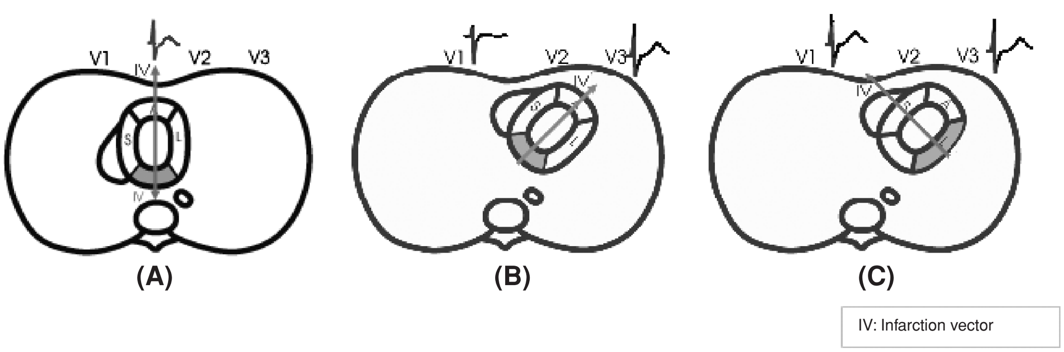

Figure 1.12 (A) The posterior (inferobasal) wall as it was wrongly considered to be placed. With this location an infarction vector of inferior infarction (segments 4 and 10 in case of very lean individuals) faces V1–V2 and explains the RS pattern in these leads. (B, C) The real anatomic position of inferior wall (inferobasal) and lateral wall infarctions. The infarction vector of inferobasal and mid-segment in lean individuals faces V3–V4 and not V1, and may contribute to the normal RS pattern seen in these leads. On the contrary, the vector of infarction of the lateral wall faces V1 and may explain RS pattern in this lead (see p. 156).

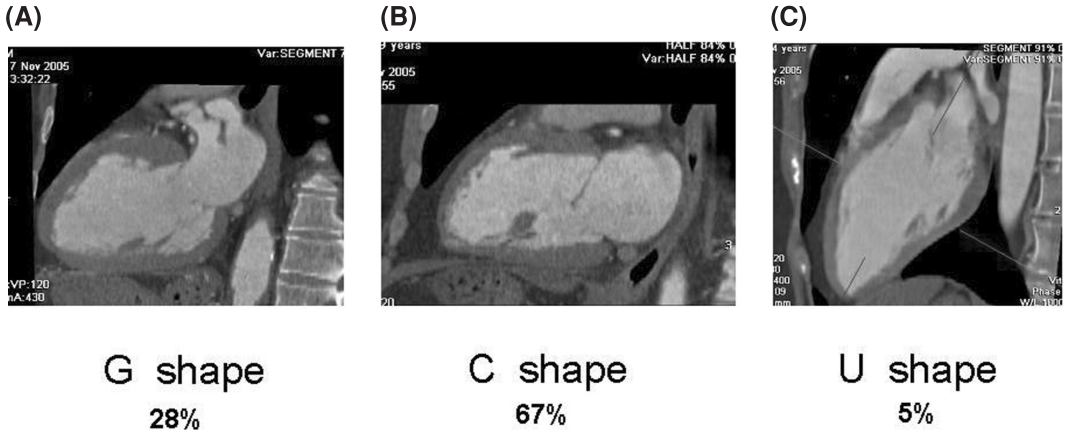

Figure 1.13 Sagittal-oblique view in case of normal-body-build subject (A) (G shape), in a man with horizontal heart (B) (C shape) and in a very lean subject (C) (U shape). We have found that the inferior wall does not bend upward in C shape (two-third of the cases), and only in very lean individuals with U shape, the largest part of the wall is posterior (5% of the cases) (C).

septal, anterior, lateral and inferior walls (Figures 1.3(1) and 1.8A; see Plate 2). Thus, the LV is divided into the basal area, the mid-area, the apical (inferior) area and the strict apex area (Figures 1.8A and 1.9).

In order to clarify the terminology of the heart walls, a committee appointed by ISHNE (International Society Holter Non-invasive Electrocardiography) has made the following recommendations (Bayés de Luna et al., 2006c):

1. Historically, the terms 'true' or 'strictly posterior' MI have been applied when the basal part of the LV wall that lies on the diaphragm was involved. However, although in echocardiography the term posterior is still used in reference to other segments of LV, it is the consensus of this report **to abandon the term 'posterior' and to recommend that the term 'inferior' be applied to the entire LV wall that lies on the diaphragm**.

2. Therefore, the **four walls of the heart are named anterior**, **septal**, **inferior** and **lateral**. This decision regarding change in terminology achieves agreement with the consensus of experts in cardiac imaging appointed by American Heart Association (AHA) (Cerqueira, Weissman and Disizian, 2002) and thereby provides great advantages for clinical practice. However, a global agreement, especially with an echocardiographic statement, is necessary.

The coronary tree: coronary angiography and coronary multidetector computed tomography

In the past, only pathologists have studied coronary arteries. In clinical practice, coronary arteriography, first performed by Sones in 1959, has been the 'gold standard' for identifying the presence or absence of coronary stenosis due to IHD, and it provides the most reliable anatomic information for determining the most adequate treatment. Furthermore, it is crucial not only for diagnosis but also for performing percutaneous coronary intervention (PCI). Very recently, new imaging techniques, especially CMDCT, are being used more and more with a great reproducibility compared with coronary angiography (O'Rourke et al., 2000; Pons-Lladó and Leta-Petracca, 2006) (Figure 1.1). CMDCT is very useful for demonstrating bypass permeability and for screening patients with risk factors. Recently, it has even suggested its utility in the triage of patients at emergency departments with dubious precordial (Hoffmann, 2006). In chronic-heart-disease patients, there are some limitations due to frequent presence of calcium in the vessel walls that may interfere with the study of the lumen of the vessel. However the calcium score alone without the visualisation of coronary arteries is important in patients with intermediate risk, in some series even

In the light of current knowledge, we would like to summarise the following:

1. Classically it was considered that the four walls of the heart are named septal, anterior, lateral and inferoposterior. The posterior wall represents the part of inferoposterior wall that bends upwards.
2. Since mid-1960s it was defended that infarction of the posterior wall presents a vector of infarction that faces V1–V2 and therefore explains RS (R) morphology in these leads (Perloff, 1964).
3. However, (a) **infarction of the inferobasal segment** (**posterior wall**) **does not usually generate a Q wave** because it depolarises after 40 milliseconds (Durrer et al., 1970) (Figure 9.5). (b) **Furthermore**, the CMR correlations have demonstrated that the **posterior wall often does not exist**, because usually the basal part of the inferoposterior wall does not bend upwards (Figure 1.13). (c) **In cases that the inferoposterior wall bends upwards**, even if the most part of inferior wall is posterior, as may be rarely seen in very lean individuals, **as the heart is located in an oblique right-to-left position**, **the vector of infarction*** is directed forwards, but to the left, and faces V3 and not V1, and therefore it **originates RS morphology in V3–V4 but not in V1**. **In reality the vector of infarction that explains the RS morphology in V1 is generated in the lateral wall** (Figures 1.11 and 1.12).
4. Currently, **the four walls of the heart have to be named septal**, **anterior**, **lateral** and **inferior**.

*The injury vector has approximately the same direction as that of the vector of ischaemia and infarction but opposite sense (see p. 35, 60 and 131 and Figures 3.6, 4.8 and 5.3). Therefore, most probably, in case of injury of the lateral wall, an ST-segment depression will be especially recorded in V1–V2, and in case of injury of the inferobasal wall, the ST-segment depression will be recorded especially in V2–V3. However, further perfusion studies, with imaging techniques in the acute phase have to be done to validate this hypothesis.

Most common names given along the time to the wall that lies on the diaphragm

1940s to 1950s (Goldberger, 1953)	Posterior wall
1960s to 2000s (since Perloff, 1964)	Inferoposterior (basal part = true posterior)
2000s (since Cerqueira, Weissman and Disizian, 2002, and Bayés de Luna, 2006)	Inferior (basal part = inferobasal)

Therefore we consider that the four walls of the heart have to be named anterior, septal, lateral and inferior.

better than exercise testing, to predict the risk of IHD. CMDCT has some advantages in case of complete occlusion (Figure 1.1G) and in detecting soft plaques. It is also useful for the exact quantification of the lumen of occluded vessel that is comparable with intravascular ultrasound (see Figure 1.1H). However, it is necessary to realise the need to avoid repetitive explorations form an economical point of view and also to avoid possible side-effects due to radiation. A clear advantage of invasive coronary angiography is that it is possible, and this is very important especially in the acute phase, to perform immediately a PCI.

The perfusion of the heart walls and specific conduction system

The myocardium and specific conduction system (SCS) are perfused by the right coronary artery (RCA), the left anterior descending coronary artery (LAD) and the circumflex coronary artery (LCX). Figure 1.1 shows the great correlation of coronary angiography and CMDCT in normal coronary tree and some pathologic cases.

Figures 1.14B–D show the perfusion that the different walls with their corresponding segments receive from the three coronary arteries. The areas with common perfusion are coloured in grey in

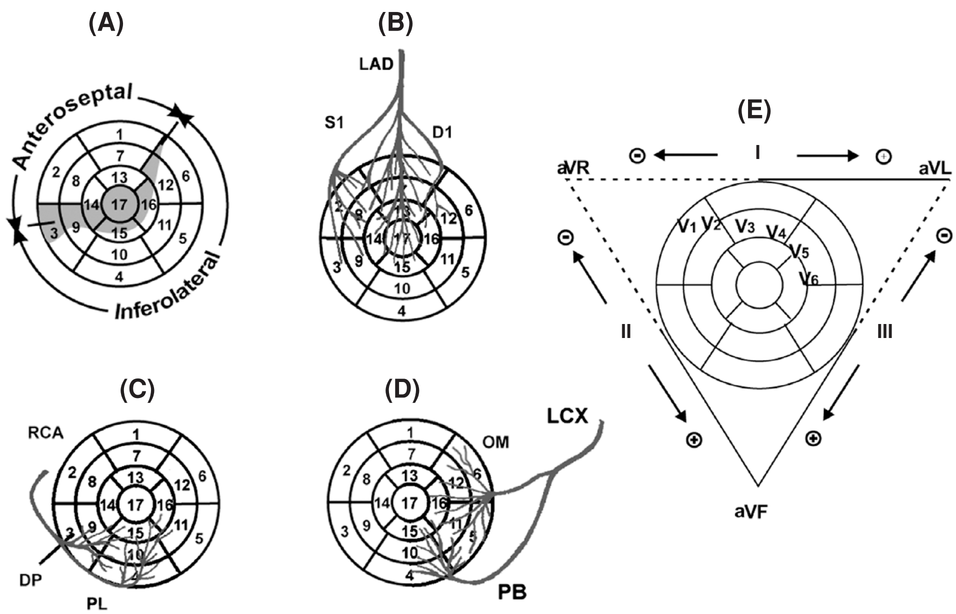

Figure 1.14 According to the anatomical variants of coronary circulation, there are areas of shared variable perfusion (A). The perfusion of these segments by the corresponding coronary arteries (B–D) can be seen in the 'bull's-eye' images. For example, the apex (segment 17) is usually perfused by the LAD but sometimes by the RCA or even the LCX. Segments 3 and 9 are shared by LAD and RCA, and also small part of mid-low lateral wall is shared by LAD and LCX. Segments 4, 10 and 15 depend on 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. (E) Correspondence of ECG leads with the bull's-eye image. Abbreviations: LAD, left anterior descending coronary artery; S1, first septal branch; D1, first diagonal branch; RCA, right coronary artery; PD, posterior descending coronary artery; PL, posterolateral branch; LCX, left circumflex coronary artery; OM, obtuse marginal branch; PB, posterobasal branch.

Figure 1.14A. Figure 1.14E shows the correlation of ECG leads with the bull's-eye image (Bayés, Fiol and Antman, 2006). **The myocardial areas perfused by three coronary arteries are as follows** (Candell-Riera et al., 2005; Gallik et al., 1995):

- **Left anterior descending coronary artery (LAD) (Figure 1.14B)**. It perfuses the anterior wall, especially via the diagonal branches (segments 1, 7 and 13), the anterior part of the septum, a portion of inferior part of the septum and usually the small part of the anterior wall, via the septal branches (segments 2, 8 and part of 14, 3 and 9). Segment 14 is perfused by LAD, sometimes shared with the RCA, and also parts of segments 3 and 9 are shared with the RCA. Segments 12 and 16 are sometimes perfused by the second and third diagonals and sometimes by the second obtuse branch of LCX. Frequently, the LAD perfuses the apex and part of the inferior wall, as the LAD wraps around the apex in over 80% of cases (segment 17 and part of segment 15).
- **Right coronary artery (RCA) (Figure 1.14C)**. This artery perfuses, in addition to the RV, the inferior portion of the septum (part of segments 3 and 9). Usually, the higher part of the septum receives double perfusion (LAD + RCA conal branch). Segment 14 corresponds more to the LAD, but it is sometimes shared by both arteries (see before). The RCA perfuses a large part of the inferior wall (segment 10 and parts of 4 and 15). Segments 4 and 10 can be perfused by the LCX if this artery is of the dominant type (observed in 10–20% of all cases), and at least part of segment 15 is perfused by LAD if this artery is long. Parts of the lateral wall (segments 5, 11 and 16) may, on certain occasions, pertain to RCA perfusion if it is very dominant. Sometimes segment 4 receives double perfusion (RCA + LCX). Lastly, the RCA perfuses segment 17 if the LAD is very short.
- **Circumflex coronary artery (LCX) (Figure 1.14D)**. The LCX perfuses most of the lateral

wall – the anterior basal part (segment 6) and the mid and low parts of lateral wall shared with the LAD (segments 12 and 16) and the inferior part of the lateral wall (segments 5 and 11) sometimes shared with RCA. It also perfuses, especially if it is the dominant artery, a large part of the inferior wall, especially segment 4, on rare occasions segment 10, and part of segment 15 and the apex (segment 17).

The double perfusion of some parts of the heart explains that this area may be at least partially preserved in case of occlusion of one artery and that in case of necrosis the involvement is not complete (no transmural necrosis).

Both acute coronary syndromes (ACSs) and infarcts in chronic phase affect, as a result of the occlusion of the corresponding coronary artery, one part of the two zones into which the heart can be divided (Figure 1.14A): (1) the **inferolateral** zone, which encompasses all the inferior wall, a portion of the inferior part of the septum and most of the lateral wall (**occlusion of the RCA or the LCX**); (2) the **anteroseptal** zone, which comprises the anterior wall, the anterior part of the septum and often a great part of inferior septum and part of the mid-lower anterior portion of lateral wall (**occlusion of the LAD**). In general, the LAD, if it is large, as is seen in over 80% of cases, tends to perfuse not only the apex but also part of the inferior wall (Figures 1.1 and 1.14).

The occlusion of a coronary artery may affect only one wall (anterior, septal, lateral or inferior) or, more often, more than one wall. ACSs and infarcts in their chronic phase, which affect only one wall, are uncommon. Even the occlusion of the distal part of the coronary arteries usually involves several walls. For example, the distal LAD affects the apical part of anterior wall but also the apical part, even though small, of the septal, lateral and inferior wall (Bogaty et al., 2002), and the distal LCX generally affects part of the inferior and lateral walls. In addition, an occlusion of the diagonal artery, although fundamentally affecting the anterior wall, often also involves the middle anterior part of the lateral wall and even the occlusion of the first septal branch artery, or a subocclusion of the LAD encompassing the septal branches involves part of the septum and often a small part of the anterior wall. Probably, the occlusion of oblique marginal (OM) (part of the lateral wall) or distal branches of a non-dominant RCA and LCX (part of the inferior wall) involves only a part of a single wall.

In fact, **whether ACSs or established infarctions involve one or more walls has a relative importance. What is most important is their extension, related mainly to the site of the occlusion and to the characteristics of the coronary artery (dominance, etc.)**. Naturally, on the basis of all that was previously discussed, large infarcts involve a myocardial mass that usually corresponds to several walls, but the involvement of several walls is not always equivalent to a large infarct, as we have already commented. For instance, the apex, although a part of various walls, is equivalent to only a few segments. Therefore **knowing what segments are affected allows us to better approximate the true extension of the ventricular involvement** (Cerqueira, Weissman and Disizian, 2002). Lastly, although in many cases multivessel coronary disease exists, this does not signify that a patient has suffered more than one infarct.

Consequently, in order to better assess the prognosis and the extent of the ACSs, and infarcts in the chronic phase, it is very important in the acute phase to establish the correlation between the ST-segment deviations/T changes and the site of occlusion and the area at risk (p. 66), and in the chronic phase between leads with Q wave and number and location of left-ventricular segments infarcted (p. 139) (Figures 1.8 and 1.9).

The perfusion of SCS structures is as follows:

(**a**) **The sinus node** and the sinoatrial zone by the RCA or the LCX (approximately 50% in each case)

(**b**) **The AV node** perfused by the RCA in 90% of cases and by the LCX in 10% of cases

(**c**) **The right bundle branch and the anterior subdivision of the left bundle branch** by the LAD

(**d**) **The inferoposterior division** of the left bundle branch by septal branches from the LAD and the RCA, or sometimes the LCX

(**e**) **The left bundle branch** trunk receiving double perfusion (RCA + LAD)

This information will be useful in understanding when and why bradyarrhythmias and/or intraventricular conduction abnormalities may occur during an evolving ACS (see 'Arrhythmias and intraventricular conduction blocks' in ACS p. 250).