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REVIEW

Left Ventricular Anatomy: Its Nomenclature, Segmentation, and Planes of Imaging

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The American Heart Association recommends a model of the left ventricular myocardium based on 17 segments. The model is accepted and used by imagers in nuclear medicine, echocardiography, magnetic resonance imaging, and, more recently, in computed tomography. Some problems persist with the orientation and presentation of the planar imaging views between the modalities and with their registration with the segmental model. These problems would be eased if the ''anterior'' wall were to be called the superior wall, which is attitudinally correct. It would follow that the ''anterior descending'' and ''posterior descending'' arteries would be known as the superior and inferior interventricular arteries. This is also more correct anatomically, as is the need to describe the papillary muscles of the mitral valve as being positioned superiorly and inferiorly. In this review, we discuss these currently existing problems and make a plea for more stringent description and display of the planes used in imaging. Clin. Anat. 22:77–84, 2009.

Key words: left ventricle; cardiac anatomy; cardiac imaging

INTRODUCTION

Cardiac imaging by selective X-ray angiography, nuclear medicine, echocardiography, and magnetic resonance imaging has now been augmented by computed tomography. Each technique has its strengths and weaknesses. A frequent and important application of all of them is the assessment of left ventricular function and viability. All the modalities, except angiography, can produce three-dimensional sets of data, but for analysis the left ventricle is usually shown as a series of planar views. The display of these views, and the words used to describe them, is not fully consistent between the modalities. To facilitate clinical integration, an expert committee convened by the American Heart Association recommended that the left ventricle be partitioned into 17 labeled segments of roughly equal mass (Cerqueira et al., 2002). The committee drew on existing descriptions, originally from nuclear cardiology and later from echocardiography, of various segmental systems. This model is unequivocally useful, and has been generally accepted. It is our opinion, nonetheless, that it has neither been fully reconciled with the planes used for imaging, nor do the terms suggested comply with the basic rules of anatomy. These, of course, demand that any structure be described relative to the planes of the so-called anatomical position.

In this review, we suggest that a simple change in just one of the terms suggested by the American Heart Association is sufficient to clarify the situation, namely that the surface of the heart opposite to that described as inferior, but currently described as anterior, be appropriately labeled as superior.

In our review, we will be discussing axes and planes. Any axis is a straight line. Its orientation in space, therefore, can be defined by just two points. It follows that the orientation of any flat plane can be defined by three points. Orthogonal planes, by definition, are at right angles to each other. In any

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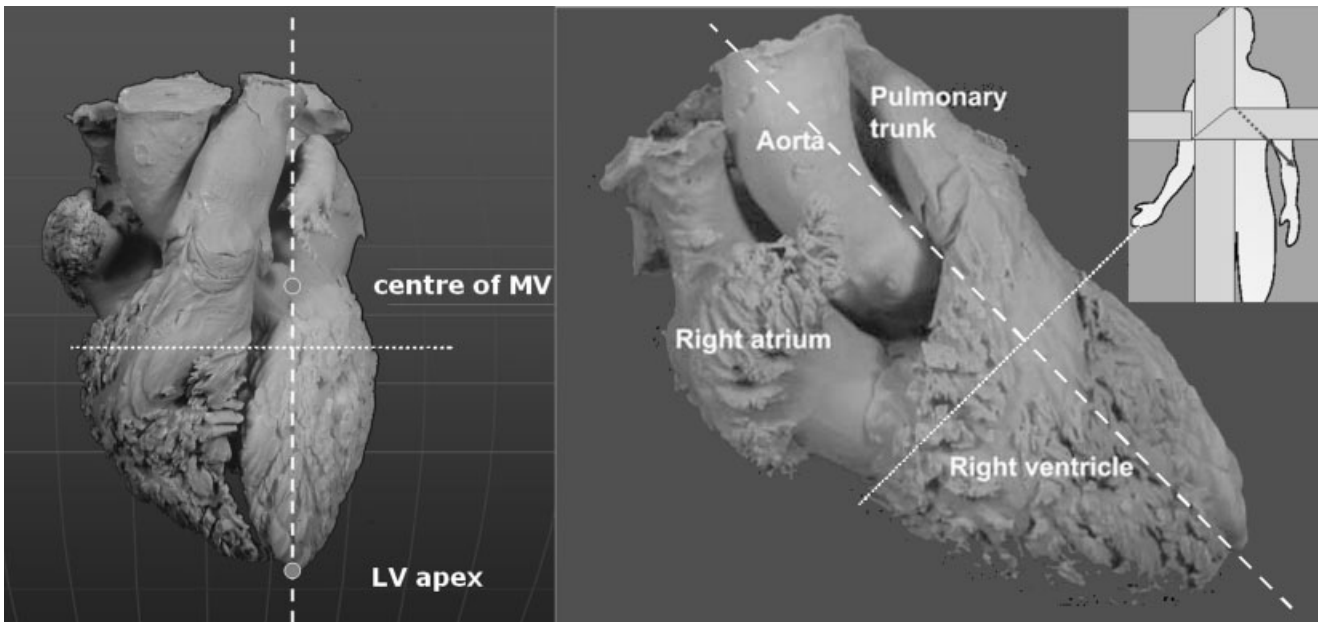

Fig. 1. The left panel shows the heart in its ''Valentine'' position, with the long axis of the left ventricle and its defining points (dashed line) and a short axis (dotted line). In the right panel, we have positioned the heart in attitudinally appropriate fashion, showing the angulation of the ventricular axes relative to the axes of the body.

three-dimensional object, there can be no more than three mutually orthogonal planes. The standard orthogonal planes of the body are the coronal, running from side to side, sagittal, running from front to back, and transverse, which is along the short axis of the body. It is the position of structures relative to these planes that should be used for their description.

GENERAL LEFT VENTRICULAR ANATOMY

That the heart is arguably the least symmetrical organ of the body does not help its description in classical anatomical terms. It has a degree of symmetry only when viewed in isolation and positioned on its apex (Fig. 1, left). Regrettably, it is the use of descriptive adjectives based on this ''Valentine'' orientation, rather than on the location of the heart within the body, which have become accepted as the norm. The axis of left ventricular symmetry passes along the bore of its conical shape, this line being skewed relative to the standard planes of the body (Fig. 1, right). The axis itself can be defined by two points, namely the ventricular apex and the middle of the mitral valve (Fig. 1, left). In clinical practice, all the modalities refer to this as the long axis. It deviates forward from the long-axis coronal plane of the body, and downward below the transverse plane. Any planar view along this axis is generically considered a long axis view. It follows that any planar view at right angles to any point on the long axis of the left ventricle is called a short axis view.

The angulation of the long axis makes it difficult to apply standard anatomical terms to the four walls of the ventricle. The inferior wall rests against the diaphragm below it. It has long been called the posterior wall, reflecting the fact that morphologists have tended to view the heart in the Valentine orientation. Only recently moves have been made to rename it the inferior wall (Cosío et al., 1999; Ho and Anderson, 1999; Cook and Anderson, 2002; Bayes de Luna et al., 2006). Opposite to the inferior wall is the superior wall, which in a clinical setting is usually described as the anterior wall. In truth, there is a variable degree of anterior slope to this wall, and it does present itself when the heart is exposed by dissection through the sternum. This is simply because the majority of the anterior wall of the left ventricle is formed by the septum. The attitudinally appropriate description for any structure opposite to the one that is inferior is superior. It is an inexorable conclusion, therefore, that the wall of the left ventricle opposite to the inferior one must be superior. Hence, we will use this term in our ongoing discussions.

The part of the wall dividing the left ventricle from the right ventricle is known, sensibly and appropriately, as the septum, the term carrying no particular spatial inference. As already indicated, it is the most anterior wall of the left ventricle. Opposite it is the true posterior left ventricular wall. This is known clinically as the lateral wall, and it is reasonable to retain this term. Any attempt to change its name would be confusing because of the use of the previous use of ''posterior'' to describe the true inferior wall. In Figure 2, we show our suggested attitudinally appropriate nomenclature applied to the model proposed

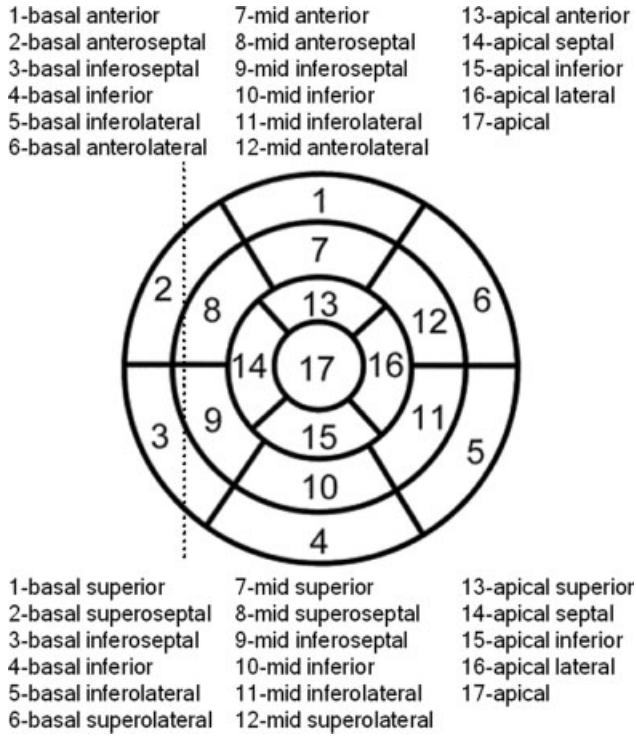

Fig. 2. The cartoon shows the 17 segment model of the left ventricle proposed by the American Heart Association, with the original nomenclature for the segments given above. Below, we show the attitudinally appropriate terminology. The dotted line is the general orientation of the ventricular septum, to compare with Fig. 3.

by the American Heart Association and compared with their terminology.

THE ORIENTATION OF THE SEPTUM AND THE SHORT AXIS VIEWS

Although the plane of the short axis is angled downward, it is sensible to have the top of the image pointing as superiorly as possible. This is how the model proposed by the American Heart Association presents itself, being a ''bulls-eye'' depiction of a series of short axis views, this being a common form of representation with its origins in nuclear medicine. With the renaming of the wall opposite to the inferior segment as superior, its nomenclature is consistent. The general orientation of the septum is vertical, shown by the dotted line in Figure 2. This fact allows us to verify its orientation against the automated software of nuclear medicine, and many installations using computed tomography, in which the top of the image is locked into a superior orientation (Fig. 3, left and center: the dotted line is again the general orientation of the septum). Further reassurance comes from angiograms viewed in the left anterior oblique projection, where again the top of the image is consistently superior (Fig. 3, right). In these images, the plane of the zone of apposition between the leaflets of the mitral valve is reasonably vertical (Fig. 4, inset), and the usual descriptions of the leaflets as being anterior and posterior are valid. In anatomical terms, it is equally valid to follow the precedent of Andreas Vesalius, and consider the leaflets to be aortic and mural. As the papillary muscles each support one end of the solitary zone of apposition between these leaflets, it is more appropriate, and attitudinally correct, to name them superior, rather than anterolateral, and inferior, rather than posteromedial. It is of note that images acquired with magnetic resonance or computed tomography underline the fact that the papillary muscles become stranded at their bases, representing in the normal situation areas of noncompacted myocardium (Axel, 2004).

When the heart is imaged using magnetic resonance, the examination proceeds as a series of selected planes, during which those showing the images may cease to do so with the top positioned superiorly. In the left panel of Figure 4, the view is correctly oriented, but not infrequently a degree of counter-clockwise (Fig. 4, right) or, much more unusually, clockwise (Fig. 5, right) rotation can appear. With these rotations, the uppermost segments are not the superior (''anterior'') segments but either the supero-septal or supero-lateral parts. The other segments are similarly rotated.

In echocardiography, the standard short axial view is obtained from the parasternal window. It is not possible for this to be aimed in a truly superoinferior direction. The presentation of the image is constrained by the convention of displaying the sector produced by the ultrasonic probe with its apex uppermost. The result is a clockwise rotation from the ideal (Fig. 5, left). Thus, the uppermost segment visualized is the supero-septal one rather than the superior segment.

Such rotation of the images present no problem to the experienced imager, but it is our opinion that it can to the trainee and, at times, to the clinician who has to reconcile the results of various investigations. As the ventricle appears as a circle, misregistration between modalities is easier than in other projections. Ideally, the images should always be presented in uniform, and attitudinally appropriate, fashion.

THE LONG AXIAL VIEWS

Any view that is orthogonal to the short axis must be in line with the ventricular long axis, in other words with the midpoint of the mitral valvar orifice and the apex in plane. There are many other useful views that are not orthogonal, but we will not discuss them here, as it is the long axial views which relate best to the model recommended by the American Heart Association. As that model is a view straight at the long axis, all the long axial views can be represented as diameters across it (Fig. 6).

The Vertical Long Axis View (Fig. 6A)

This view is the vertical plane through the ventricular long axis. Its segmental representation is

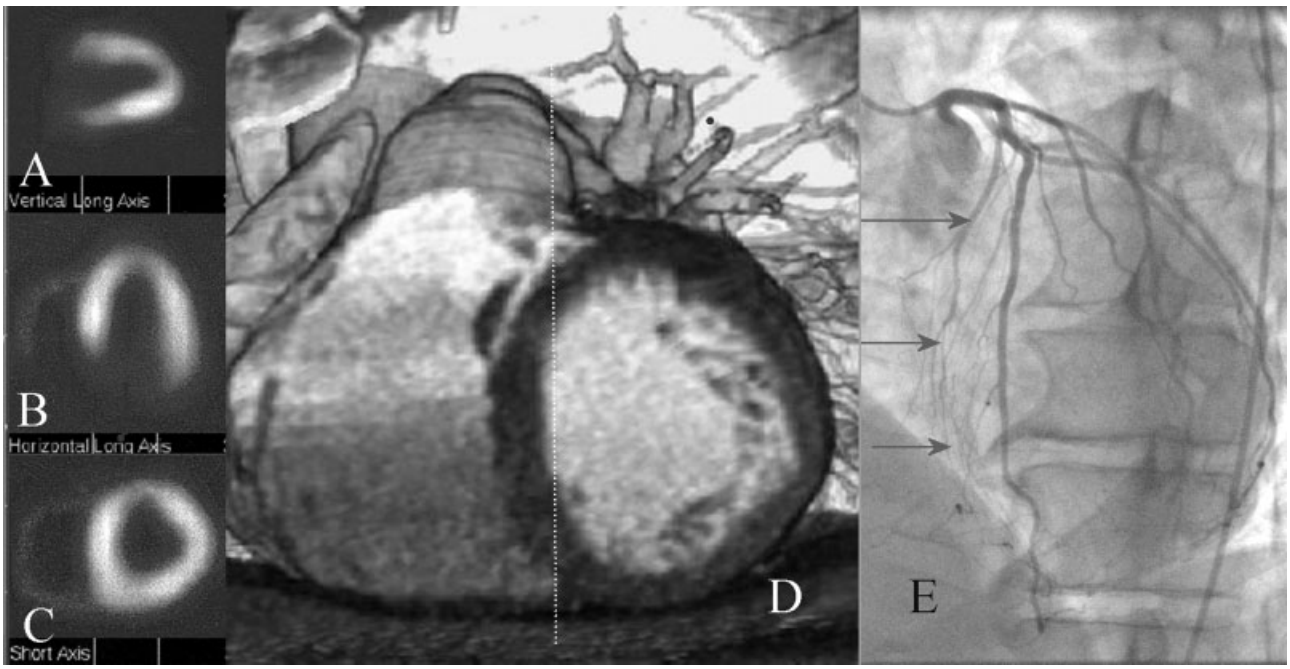

Fig. 3. These clinical images show the orientation of the septum. In the vertical long axis (**A**), horizontal long axis (**B**), and short axis (**C**) views as obtained with nuclear imaging, and in the short axis computerised tomographic scan (**D**), the septum is vertically oriented (dotted line). The left anterior oblique selective coronary angiogram is shown in Panel **E**, with the septal vessels arrowed, confirming that the septum is parallel to the spine.

straightforward. When seen in magnetic resonance images, it is displayed with the apex to the right, with the downward slope of the long axis still evident (Fig. 7a). When shown in images obtained from nuclear studies (Fig. 3A) and those obtained with computerized tomography, it has become conventional to rotate the ventricle into the horizontal. This is arguably the best orientation for display. In echocardiography, this is known as the apical two chamber view. Since it is obtained by using the ultrasonic beam directed from the apex, the convention of retaining the apex of the sector uppermost results in the ventricle itself pointing upward (Fig. 7, middle). Echocardiographic machines are not usually fitted

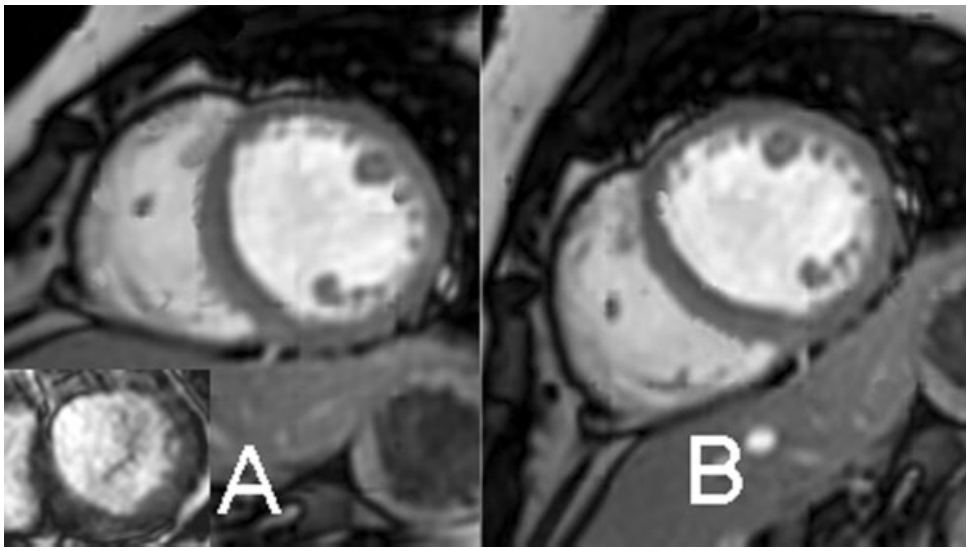

Fig. 4. In (**A**) we show a magnetic resonance short axis in correct orientation. The inset shows the zone of apposition between the leaflets of the mitral valve in their closed position. In Panel **B**, the same image is rotated. See text for further discussion.

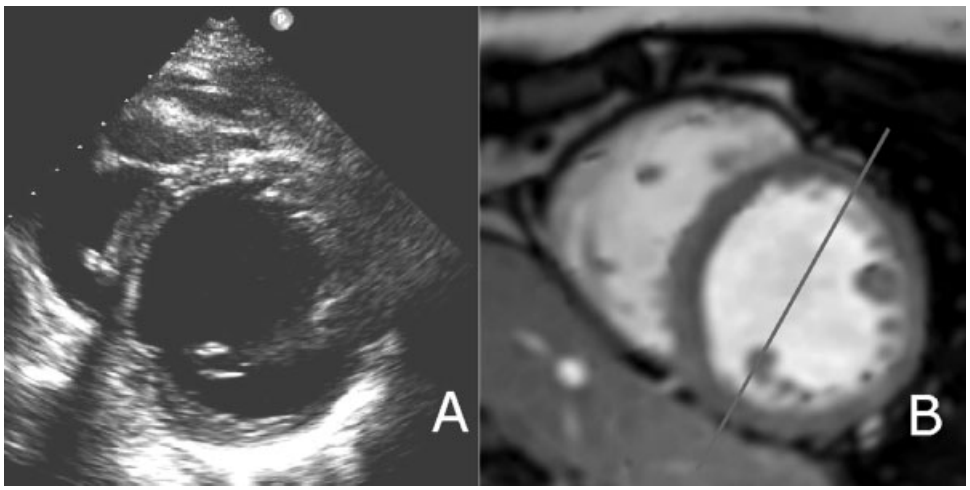

Fig. 5. An echocardiographic short axis view (**A**) is in its usual display position, and (**B**) is a magnetic resonance image seen in short axis and rotated to the same orientation. The grey line is the plane of the vertical long axis. See text for discussion.

with software to permit the rotation through 90° that would be required to produce a standardized display. The standard left ventricular angiogram obtained in 40° right anterior oblique orientation is the shadow projection of this view, and represents exactly the same segments (Fig. 7, right). The overlapping structures of the outflow tract give the erroneous impression that it is a shadow of the parasternal long axis view (see later).

The ''Four Chamber'' Views (Fig. 6B, C, D)

This is a grouping of similar views, all showing elements of both atrial and both ventricular chambers, but which have important differences between them.

Plane B is the horizontal long axis view, which is orthogonal to the vertical long axis view. It is not literally horizontal, which would make it transverse, but each line of it along the long axis is horizontal. The software currently employed for nuclear (Fig. 3B) and computerized tomographic imaging of the heart automatically generate this view. Plane C is almost the same, being angled slightly to pass through the centers of the orifices of the mitral and tricuspid valves, the tricuspid valvar orifice being slightly inferior to that of the mitral valve. This view is preferred to the horizontal long axis view by echocardiographers (Fig. 8, middle), and is often replicated by those using magnetic resonance (Fig. 8, left) and computerized tomography, as in anatomical terms it is a more satisfying view. We suggest that it is called the ''transvalvar four chamber'' view. Neither it nor the horizontal long axis view is good for segmental analysis, since both pass between segments. This has been recognized in echocardiography, where Plane D as shown in Figure 6 is used so as to identify the bisected segments more clearly (Fig. 8, right). The ''segmental four chamber'' might be a good name for this view. This suffers in that it shows much less of the right ventricle and tricuspid valve than the others, and we have noticed that it is seldom a view obtained routinely in the standard echocardiographic examination. In general (Fig. 8, left), this group of views is usually presented without comment as to their precise orientation. Those using magnetic resonance imaging also show similar nonaxial planes, and correlation between modalities can be problematical.

As for the presentation of the four-chamber group, they are closer to the transverse plane of the body than others, and in computed tomography and

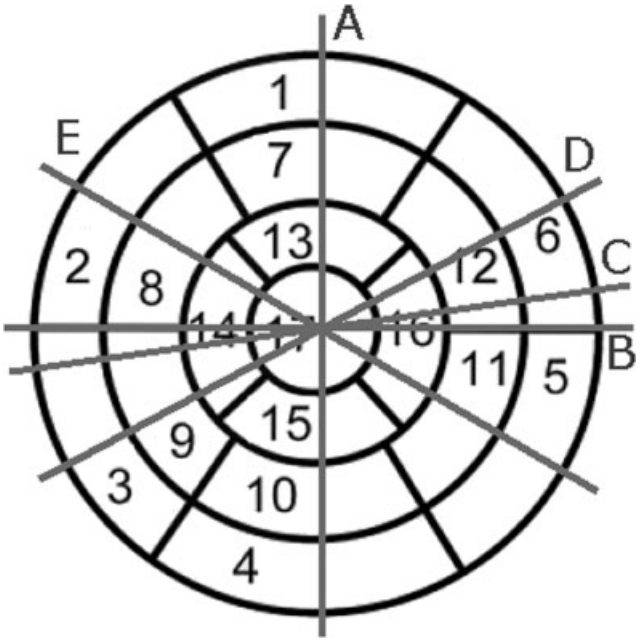

Fig. 6. The cartoon shows the planes revealing the long axial views of the left ventricle : (**A**) vertical long axial, (**B**) horizontal long axial, (**C**) transvalvular four chamber, (**D**) segmental four chamber, (**E**) left ventricular outflow tract. See text for discussion.

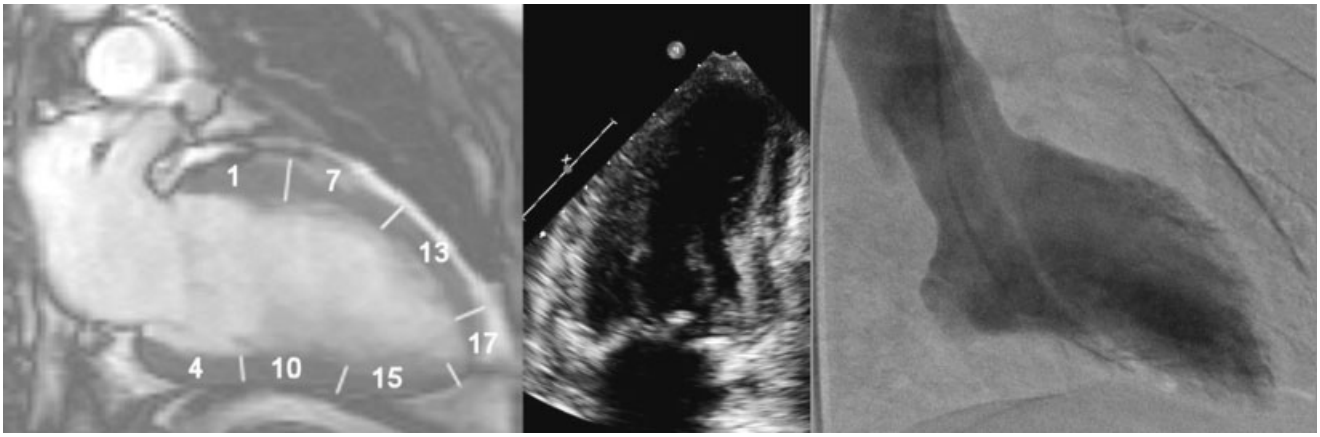

Fig. 7. The left panel shows the vertical long axis image, with its segmental pattern, as obtained using magnetic resonance imaging. The middle panel shows the apical two chamber echocardiographic view, while the right panel shows a left ventricular angiogram in right anterior oblique projection.

noncardiac ultrasound it is an established convention to view these as if from below with the top of the image oriented anteriorly. For the heart, bringing the apex to the top of the image, as in echocardiography and nuclear studies, might be best. For those interpreting the lesion seen in congenitally malformed hearts, however, the apex is now usually shown at the bottom, which is easier to relate to the equivalent angiographic projections.

The View Showing the Left Ventricular Outflow Tract (Fig. 6E)

This is a standard view obtained in the echocardiograpic examination, usually from the parasternal window, and hence it is called the parasternal long axis view (Fig. 9, left). As with all views showing the ventricular long axis it includes the midpoint of the mitral valvar orifice and the apex. Its third point of reference is the middle of the aortic valve. Properly performed, it is a good view for segmental analysis, bisecting the supero-septal and infero-lateral parts. It is seldom used in nuclear studies, but is a standard view for those using magnetic resonance or computerised tomography (Fig. 9, middle and right). It is presented in a horizontal orientation with the apex to the right, though some echocardiographers put the apex to the left.

We have noticed that, in the versions of this view obtained with magnetic resonance or computerized tomography the right ventricular cavity extends as expected to the apex, whereas in many examples of the parasternal long axis echocardiographic view, the right ventricle ends at mid-septum. The echocar-

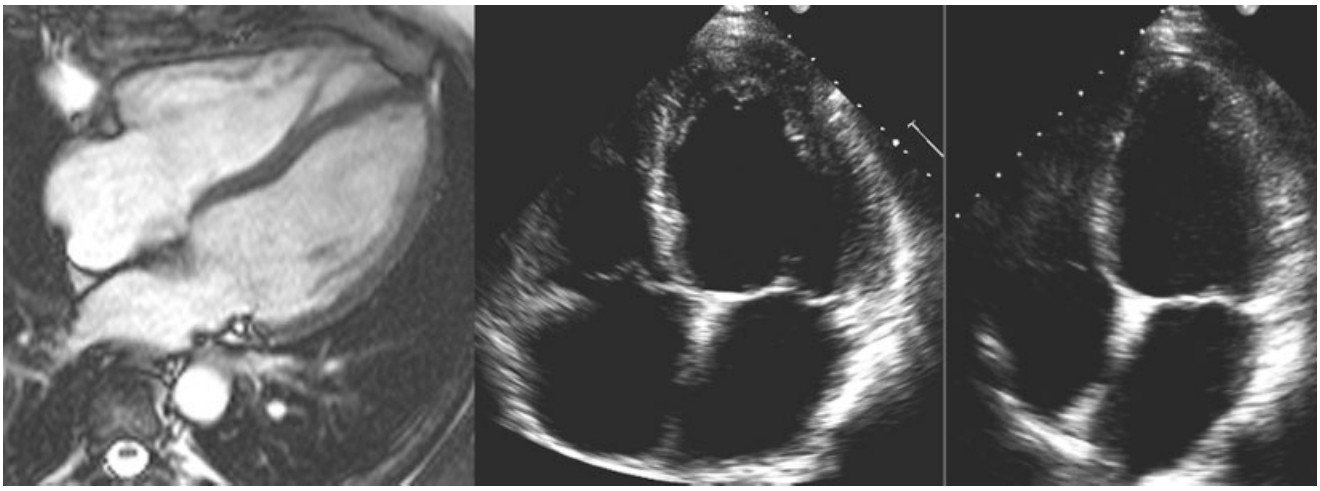

Fig. 8. In these panels, we show, to the left, the transvalvar four chamber view as obtained using magnetic resonance imaging, in the middle the echocardiographic transvalvar four chamber view, and to the right, the echocardiographic segmental four chamber view. The echocardiographic views are shown in conventional fashion, with the apex of the sector to the top. As can be seen, it would be better to rotate these images through 90° in clockwise fashion so as to produce better correlation with the magnetic resonance image.

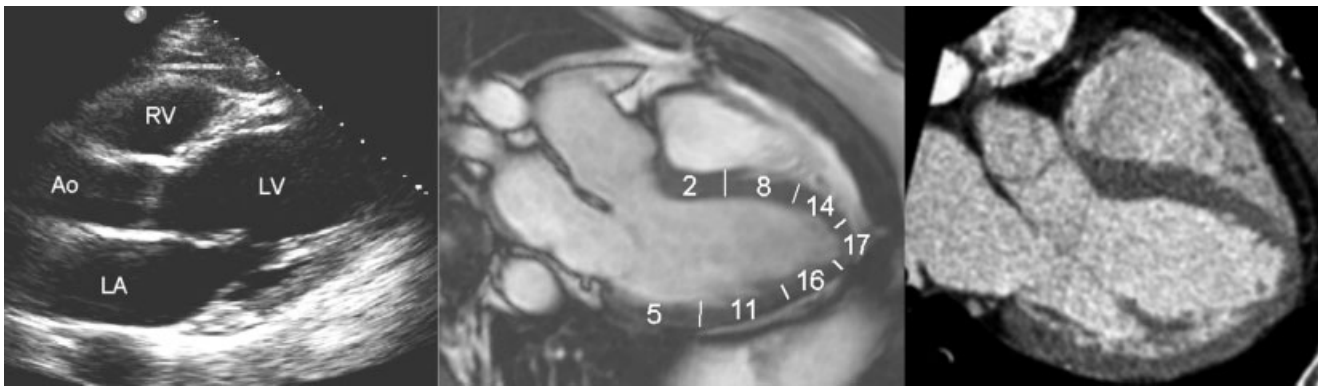

Fig. 9. These images show, to the left, the echocardiographic parasternal long axis view, in the middle the view of the left ventricular outflow tract obtained using magnetic resonance imaging, with superimposition of the segmental pattern, and to the right the comparable view of the outflow tract obtained with computerised tomography.

diographic view can also be obtained from the apical window, when this problem is not evident. We suspect the reasons for this are twofold. First, the apical portion of the right ventricular cavity is shallow when compared with its base. In this respect, the 17-segment model should not be expected to display the anatomy with total accuracy. If it is modified to show the basal part of the right ventricle as it wraps around the left ventricular outflow tract, the result is as shown in Figure 10. Second, the apex is usually not visible from the parasternal window, and the plane of the image might wander slightly to its left. As a result, the apical part of the right ventricle is easy to cut off, yet still leave the basal cavity well seen. In terms of segmental representation, the plane will still bisect segment 2, this being the segment closest to the aortic valve, but the accuracy of the rest of the outline is probably not reliable.

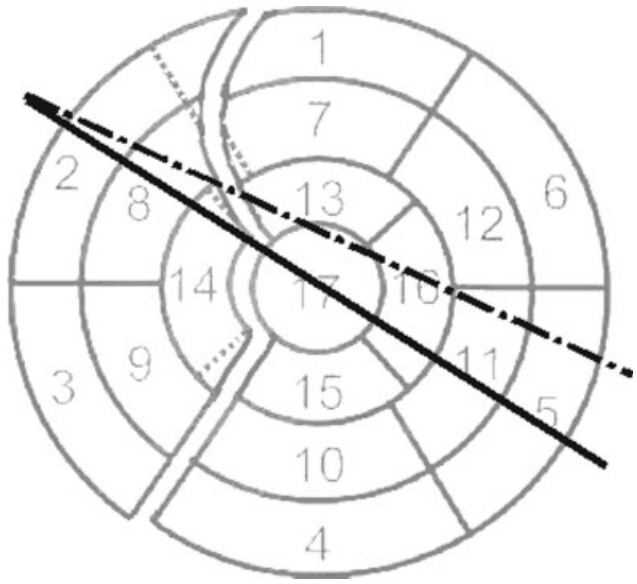

Fig. 10. The ''bulls-eye'' approach shown in Figure 2 has been modified to account for the location of the septum (see text). The solid line shows the plane of the left ventricular outflow tract, while the dotted line shows the likely position of the echo parasternal long axis section when the apex is not aligned.

THE CORONARY ARTERIES

If our suggestion is that the superior and inferior walls are so described, then it would be logical to rename the ''anterior descending'' artery the ''superior interventricular'' artery and the ''posterior descending'' the ''inferior interventricular.'' We would prefer to abandon the word ''descending'' as there is very little descent of the inferior vessel, and it is inconsistent to retain it for the superior vessel.

THE DISTRIBUTION OF THE CORONARY ARTERIES

There are several products, or descriptions of techniques, designed to unify the presentation of the anatomy of the coronary arteries with their myocardial distribution, for example, the presentation emanating from Green Lane Hospital, Auckland (Brandt et al., 1977). We are aware of one approach that uses the 17-segment model as a template (Sensky et al., 2002). Taking Figure 10 and separating the septum from the free ventricular wall gives us an image upon which the coronary arterial distribution can be drawn over the segmental model with reasonable accuracy, but without looking too artificial (Fig. 11).

CONCLUSIONS

It is the views showing the ventricular short axis that provide the mainstay of segmental analysis for most clinical modalities that image the left ventricle. Correlation between them is straightforward, provided that allowance is made for any rotation of the images. The echocardiogram is more limited, and a full set of long axial views may only be available from the apex, in which case the precise orientation of the four-chamber view must be noted. If the parasternal long axis view is used, the representation of the segments has to be interpreted with caution. The

Fig. 11. By taking the modified cartoon of the segments as shown in Figure 10, and increasing the gap between septum and free wall, it is possible to produce a template for a reasonably life-like diagram of the coronary arterial distribution.

key to correlating the various images is to describe the heart in attitudinally appropriate fashion. Unfortunately, this has rarely been the approach adopted by anatomists and pathologists over the years, these practitioners tending to remove the heart so as to place it on its apex for subsequent description. Although showing well the orientation of atrial and ventricular chambers to each other, this approach does little to help the clinician understand the structure of the heart within the body. And it is, of course, the position of the heart within the body that should have been used as the basis for description by anatomists and pathologists. Only recognition of the importance of the attitudinally appropriate approach by those teaching anatomy during the medical curriculum will prepare the students of today for appropriate interpretation of the spectacular images of the heart now produced by techniques such as magnetic resonance, computerized tomography, and echocardiography. And only recognition of the significance of the attitudinally appropriate approach by those using these modalities will produce the necessary unification of clinical nomenclature.

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