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Overview of Imaging Modalities: Pros and Cons

FLUOROSCOPY IS THE GENERAL STANDARD to perform any interventional procedure and is available all over the world. Despite the fact that soft tissue like the myocardium is not imaged at all, the ready accessibility of fluoroscopy at low cost makes it the standard imaging technique for electrophysiology (EP) procedures. Seeing the heart in standard 2D projections like anteroposterior, left anterior oblique, and right anterior oblique allows

the investigators to compute a 3D image in their heads, enabling them to be guided safely through the heart. Every novice, however, is awed by the orientation and detail an experienced interventionist is able to obtain from looking at only a single 2D picture, whereas 3D reconstructions make the orientation simpler and understandable even for laypeople.

Fluoroscopy can cause serious side effects for both investigators and patients. Being in the direct ionizing beam, the patient is exposed at maximum levels but, hopefully, will be exposed only once in a lifetime. Depending on the direction of the imaging beam, the duration of exposure, and the volume of the radiated area, the first sign of adversity is skin reddening occurring weeks after the procedure. The potential to induce malignancies by fluoroscopic exposure in interventional procedures is relatively low, although with repeat exposures this might become an issue for the individual patient. Fundamental to the application of fluoroscopy is the ALARA (as low as reasonably achievable) principle. Since the operator is the person with the highest exposure to scattered radiation, closest adherence to this principle is the best protection against radiation injury.

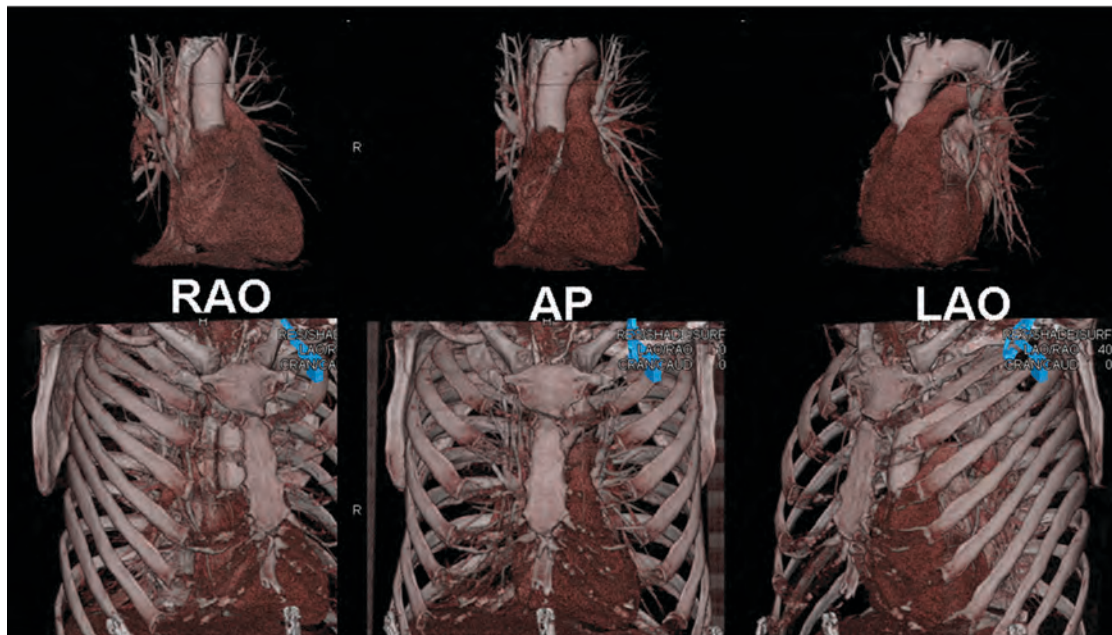


FIGURE 3.1

3D reconstruction of a CT scan of the thorax with (*upper panels*) and without (*lower panels*) removal of bony thoracic structures in right anterior oblique (RAO, *left*), anteroposterior (AP, *middle*), and left anterior oblique (LAO, *right*) projections.

3D Imaging

In recent years, several imaging techniques have been introduced into clinical practices that allow for 3D reconstruction of the heart. These imaging studies are carried out ahead of the EP study in dedicated scanners. Information transfer is then necessary to integrate the information that was acquired elsewhere into the EP study setup.

COMPUTED TOMOGRAPHY (CT)

Dedicated computer systems can generate a 3D image of the heart from a large series of 2D fluoroscopic images. Nowadays, using multislice techniques, high resolution and ultra-fast speed allow for procedure times of about five minutes. Application of 50-mL to 100-mL contrast in a timely fashion allows for delineation of the cardiac anatomy in diastole, but the high-resolution image comes at a cost of up to 12 mSv (equivalent to 100–600 chest X-rays). Another potential limitation is that imaging by CT angiography can only be obtained in areas where contrast has actually arrived, a problem that is especially apparent in patients with arrhythmia or congenital heart disease for whom contrast transit times can vary substantially (Figure 3.1).

CARDIAC MAGNETIC RESONANCE (CMR) IMAGING

In contrast to CT imaging, CMR imaging uses no ionizing radiation but utilizes magnetic fields to align the nuclear magnetization of (mostly) hydrogen atoms in the water content of the body. Although contrast agents might need to be used, specific imaging sequences can be performed that allow the blood to act as the contrast agent, such that contrast transit times no longer matter. A clear limitation of the CMR technology is the exclusion of patients with implanted ferromagnetic material such as pacemakers/implantable cardioverter-defibrillators (ICDs), cochlear implants, or aneurysm clips. Vascular stents give typically black holes, but both titanium and stainless steel stents can be safely imaged (Figure 3.2).

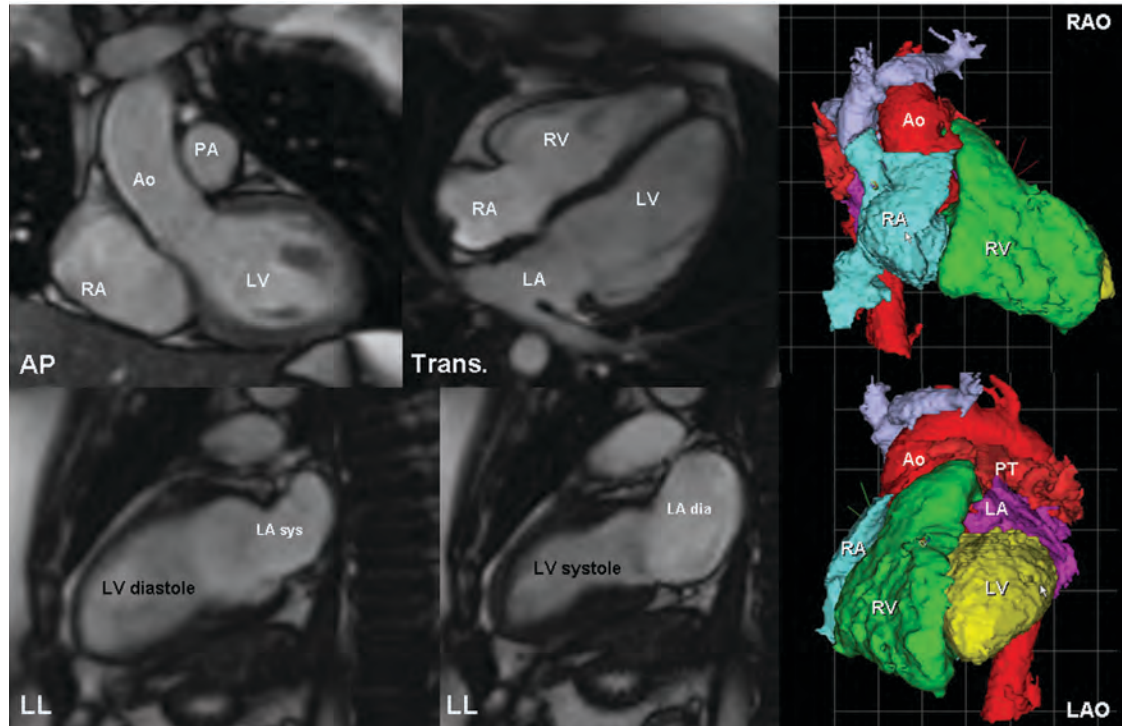


FIGURE 3.2

2D reconstructions of a non-contrast cardiac magnetic resonance acquisition of a normal heart in anteroposterior (AP) and transversal (**trans.**) projection, as well as in left lateral (LL) view showing left ventricular (LV) systolic and diastolic filling. The two *right panels* show a 3D reconstruction of the same data set on the Polaris software for 3D reconstruction in RAO and LAO projection. RA = right atrium; LA = left atrium; RV = right ventricle; LV = left ventricle; Ao = aorta; PT = pulmonary trunk.

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Positioning of Standard Catheters: Electrophysiology and Anatomy

AT THE BEGINNING OF AN INVASIVE electrophysiological (EP) study, electrophysiologists need to identify the individual patient's anatomy by evaluating standard fluoroscopy images. The heart and the spatial relationships of its chambers, however, are not easy to see, since cardiac tissue can only be displayed as a shadow.

General Aspects

In the upper panels of Figure 4.1, the heart is depicted in right anterior oblique (RAO) 30°, anteroposterior (AP), and left anterior oblique (LAO) 40° projections, with an endocast of a human heart in the corresponding position in the lower panels. When only the outline of the heart can be seen, the exact locations of specific sites within the heart are very difficult to ascertain.

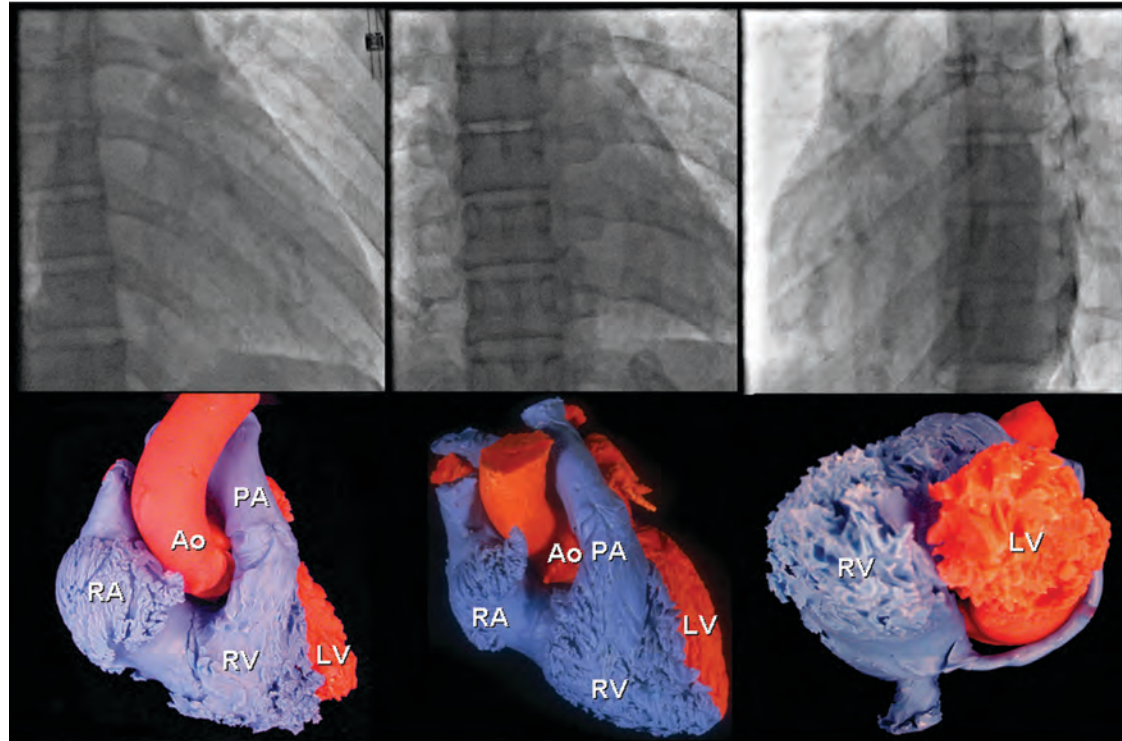


FIGURE 4.1

Upper panels show a “plain” heart in RAO 30°, AP and LAO 40° projection without any catheters (“naked heart”). *Lower panels* depict endocasts of a human heart in corresponding projections.

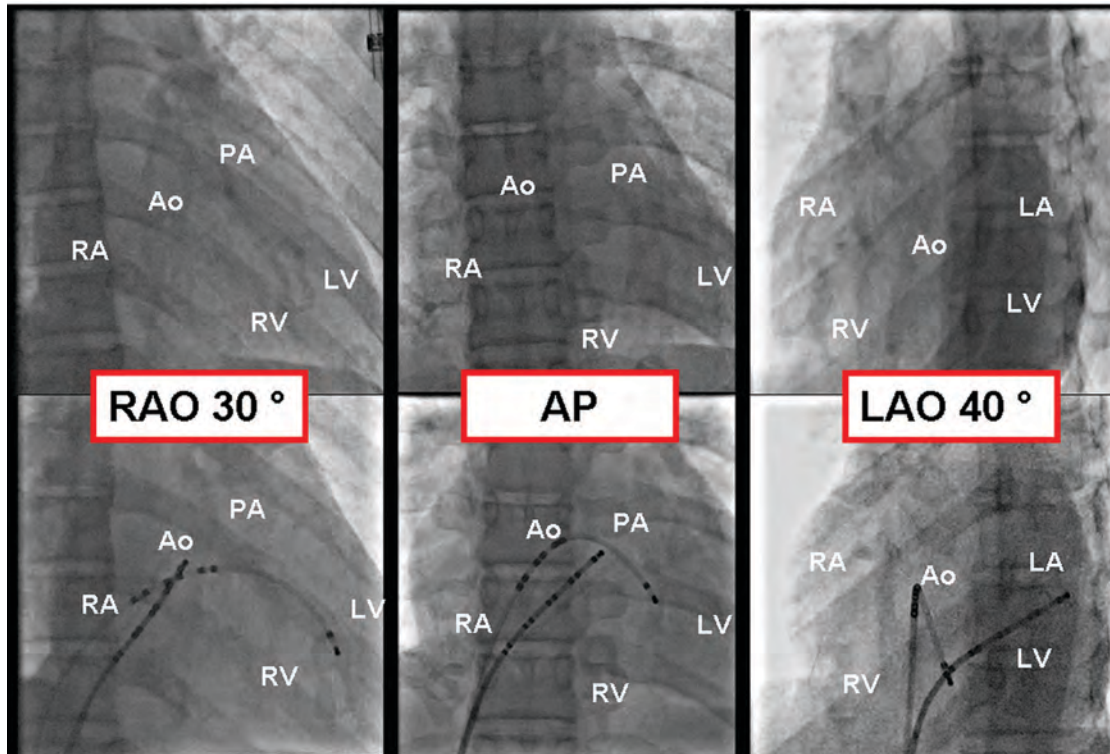


FIGURE 4.2

Same projections as in upper panel in Figure 4.1 but with CS and His catheters in place.

In conventional EP studies, catheters are positioned in locations that allow for recording of intracardiac electrograms and stimulation from strategic areas inside the heart. Typical examples are catheters at the right ventricular apex (RVA), at the His bundle (HIS), or inside the coronary sinus (CS). Simultaneous to the recording of the electrical signals from these catheters, the locations of the catheters and their shafts allow for a more detailed depiction of the heart by using these structures as landmarks (Figure 4.2).

5

Electrical Anatomy and Accessory Pathways

IN THIS CHAPTER WE BEGIN BY REVIEWING the structure of the normal conduction system and the configuration of the atrioventricular junctions. Building upon the fundamentals, we discuss the anatomy and electrophysiological properties of accessory pathways, including unusual types, and the access routes to reach them.

The Cardiac Conduction System

Although much has been written about specialized internodal tracts connecting the sinus node to the atrioventricular node, the myocardium between the nodes bears no histological characteristics that resemble insulated conduction bundles. Mainly, the internodal myocardium is arranged in broad bands that surround the orifices of the large veins, the tricuspid valve, and the oval fossa. Bands like the rim of the oval fossa and the terminal crest are raised ridges on the endocardial aspect and tend to have an orderly alignment of the myocytes approximating to myocardial strands visible on gross dissection. Bachmann's bundle and other interatrial bundles, small as well as large, are not insulated by fibrous sheaths, nor do they have well-defined origins and terminations. In these, the myocardial strands also tend to be aligned along the length of the bundles (Figure 5.1).

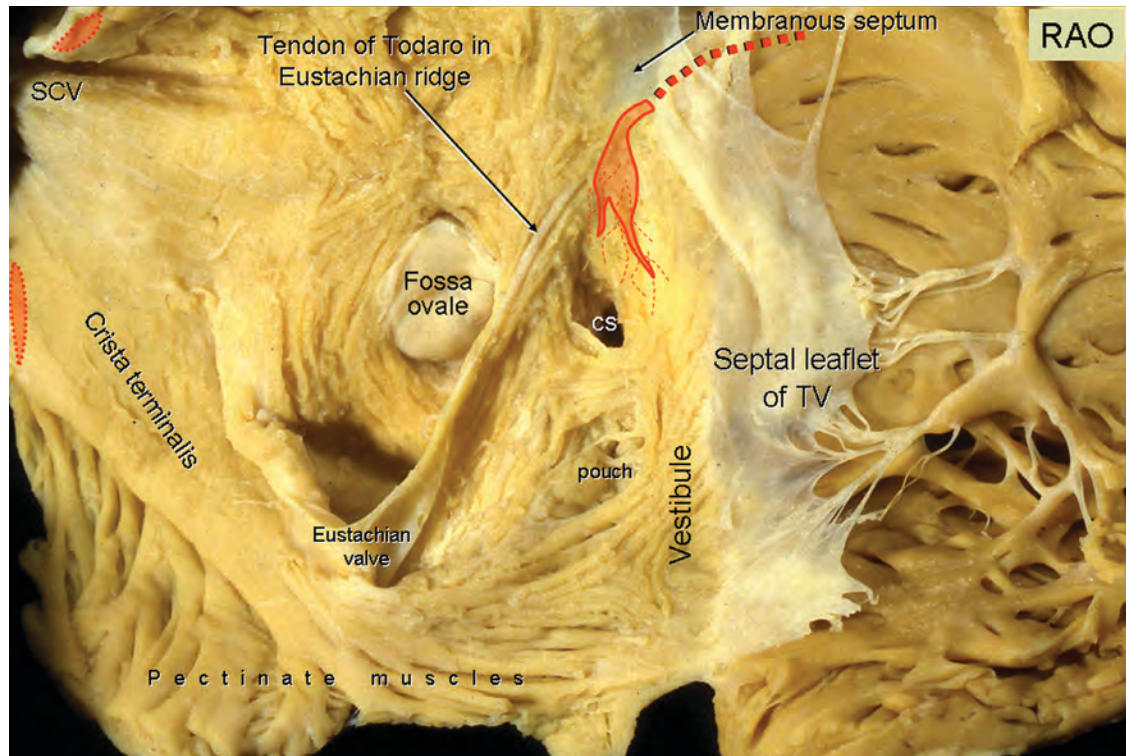


FIGURE 5.1

The endocardium lining the right atrium has been dissected away and the atrial wall displayed to show the gross arrangement of the myocardial strands in the internodal region. Muscle bundles such as the terminal crest and pectinate muscles show strands that are better aligned longitudinally. The sinus node (**colored ovals**) is depicted as having been bisected by the cut through the superior caval vein (SCV). The location of the compact atrioventricular node and His bundle at the apex of the triangle of Koch is shown as an irregular shape with the **fine broken lines** representing the transitional cell zone. The **bold broken line** represents the continuation of the atrioventricular conduction bundle. **cs** = coronary sinus; **RAO** = right anterior oblique; **TV** = tricuspid valve.

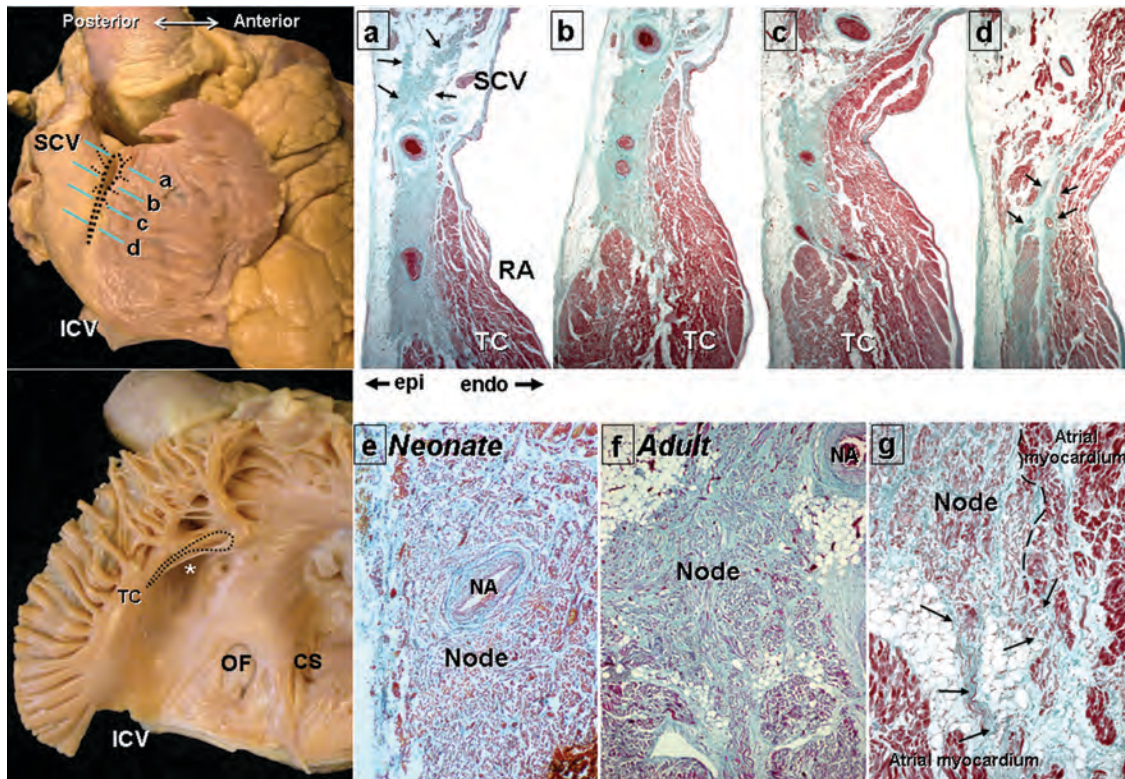


FIGURE 5.2

The two pictures of a heart specimen show the epicardial (*upper panel*) and endocardial aspects of the right atrium with the locations of the sinus node superimposed (*dotted shape*). The **short broken lines** in the *upper panel* represent nodal extensions into atrial myocardium. The **blue lines** indicate the planes of the histologic sections. The **asterisk** on the *lower panel* marks the orifice of the superior caval vein (SCV). (a) to (d) are cross sections through the sinus node and the terminal crest (TC) with the

epicardial (**epi**) surface to the left and the endocardial (**endo**) surface to the right of each panel. Staining with Masson's trichrome stain shows the node as areas with combined red and green while ordinary atrial myocardium appears as a darker red. (a) This section through the head portion of the sinus node shows extensions of nodal cells (**arrows**) into the myocardial sleeve of the SCV. (b) and (c). The nodal body and tail taper and penetrate into the TC. (d) At its distal portion the node separates into

THE SINUS NODE

The sinus node is shaped rather like a tadpole having a head, body, and long tapering tail. It has a mean length of 13.5 mm in the adult heart. It is located at the junction between the superior caval vein and the right atrium (Figure 5.2). Usually, the node lies in the terminal groove at the anterolateral margin of the junction. The head portion is subepicardial, close to the superior margin of the terminal groove, while the tail penetrates inferiorly into the myocardium of the terminal crest to lie closer to the subendocardium. The distal portion of the tail tends to lose its compactness and fragment into clusters of specialized cells. The node is richly supplied with nerves from both the sympathetic chains and the vagus nerve. A prominent nodal artery usually penetrates the node. The specialized myocytes of the nodal cells are set in a fibrous matrix, but the node is not encased in a fibrous sheath.

small islands of nodal cells (**arrows**). (e) and (f) are high magnifications of the sinus node showing increase in fibrous tissue (**green**) amongst the nodal cells of the adult heart. (g) This closeup view of the border zone shows prongs of nodal cells (**arrows**) extending into ordinary atrial myocardium as well as a discrete border (**broken line**). CS = coronary sinus; ICV = inferior caval vein; OF = oval fossa; NA = nodal artery; RA = right atrium.

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The Left Ventricle

UNLIKE THOSE OF THE RIGHT VENTRICLE (RV), the inflow and outflow tracts of the left ventricle (LV) are at an acute angle to one another, giving the ventricle an approximately conical shape.

Anatomy

When the heart is viewed from the front, most of the LV is behind the RV with its outlet overlapping its inlet (Figure 10.1). This is because the central location of the aortic valve places the outflow tract in between the mitral valve and the ventricular septum. Its inferior wall is in contact with the diaphragm.

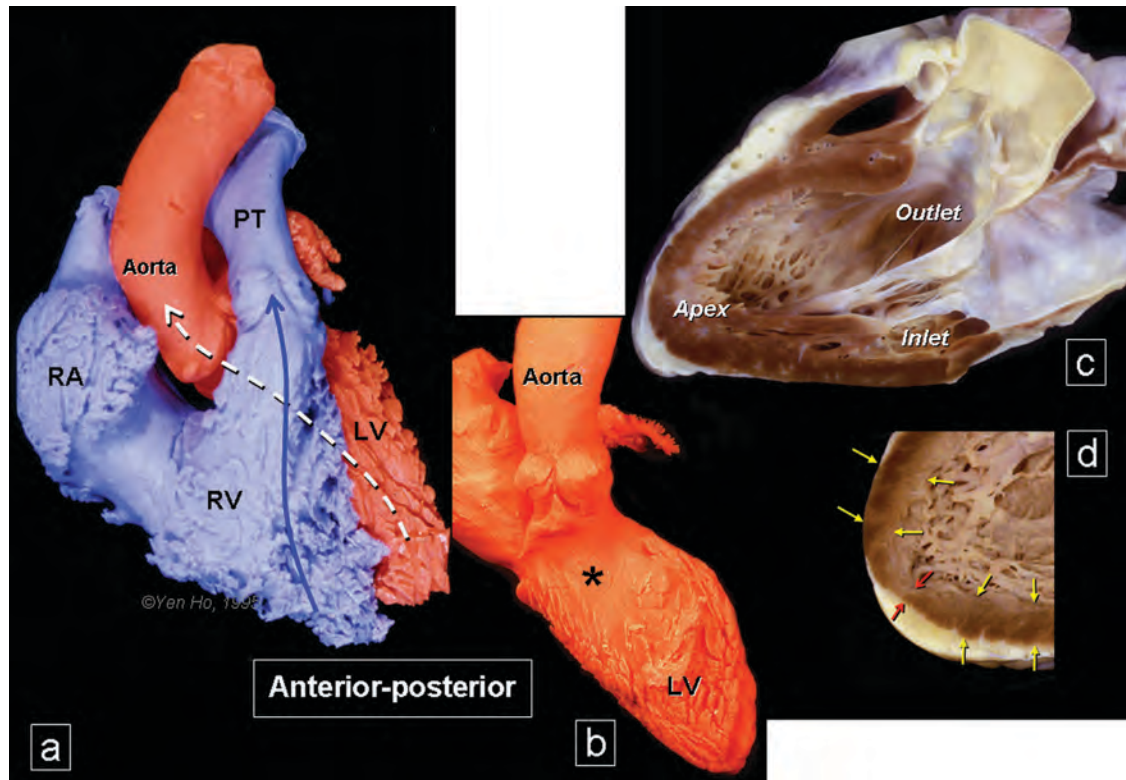


FIGURE 10.1

(a) Much of the left ventricle (LV) lies behind the right ventricle (RV). The LV outflow tract is behind the outflow tract of the RV (arrows). (b) The septal surface (asterisk) below the aortic valve is smooth. (c) The three portions of the LV; the outlet lies between the septum and the inlet. (d) The LV wall (yellow arrows) tapers to become very thin at the apex (red arrows). PT = pulmonary trunk; RA = right atrium.

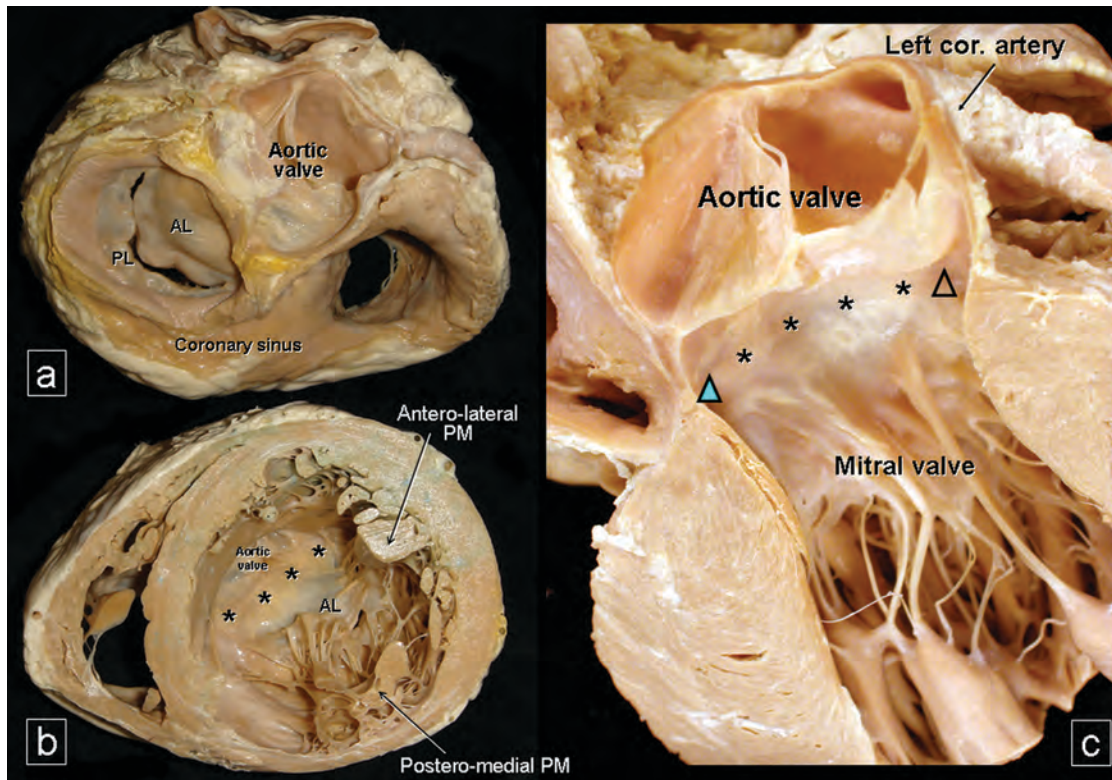


FIGURE 10.2

(a) The anterior (AL) and posterior (PL) leaflets of the mitral valve viewed from the atrial aspect. The aortic valve is immediately adjacent to the mitral valve. (b) This apical view of a heart with dilated left ventricle and previous infarction shows the area of fibrous continuity (asterisks) between the aortic and mitral valves. (c) This longitudinal section shows the area of fibrous continuity from the front. At either end are the fibrous trigones (triangles) with the right trigone colored blue. PM = papillary muscle.

The hinge (annulus) of the mitral leaflets at the entrance to the inlet has a very limited attachment to septal structures (Figure 10.2). Compared to that of the tricuspid valve, the septal hinge line of the mitral valve is further away from the apex, and it does not have a septal leaflet. Its two leaflets are referred to as anterior and posterior, but the designations do not truly reflect their locations. Alternative terms are *aortic* and *mural*, respectively. Two-thirds of the valve annulus is at the parietal atrioventricular junction whereas one-third is the span of fibrous continuity between the anterior leaflet and the aortic valve (see Figure 10.2).

12

Pitfalls and Troubleshooting

SOMETIMES EVEN RELATIVELY EASY tasks are difficult to achieve during an electrophysiological (EP) study. Most of the time, alternative access ways can save the day whenever the standard way does not work. Sometimes just a small hint can make all the difference.

Difficulty to Reach Tricuspid Annulus

Especially when there is a very long inferior isthmus, a very annular position for the catheter can be difficult to achieve. When looking in a right anterior oblique (RAO) projection the distance from the coronary sinus (CS) ostium, judged by the turning point of the CS catheter, to the inferior vena cava (IVC), where all the catheter shafts gather together, the accurate choice of reach for the ablation catheter can be made. In case of failure, a large loop along the free wall of the right atrium (RA) allows the catheter to reach the tricuspid annulus in an inverted fashion (Figure 12.1). By extending the curve when the inversion is complete, firm contact can be made.

An alternative is to use long, preformed, or steerable sheaths that stabilize the catheter and ensure stable catheter-tissue contact.

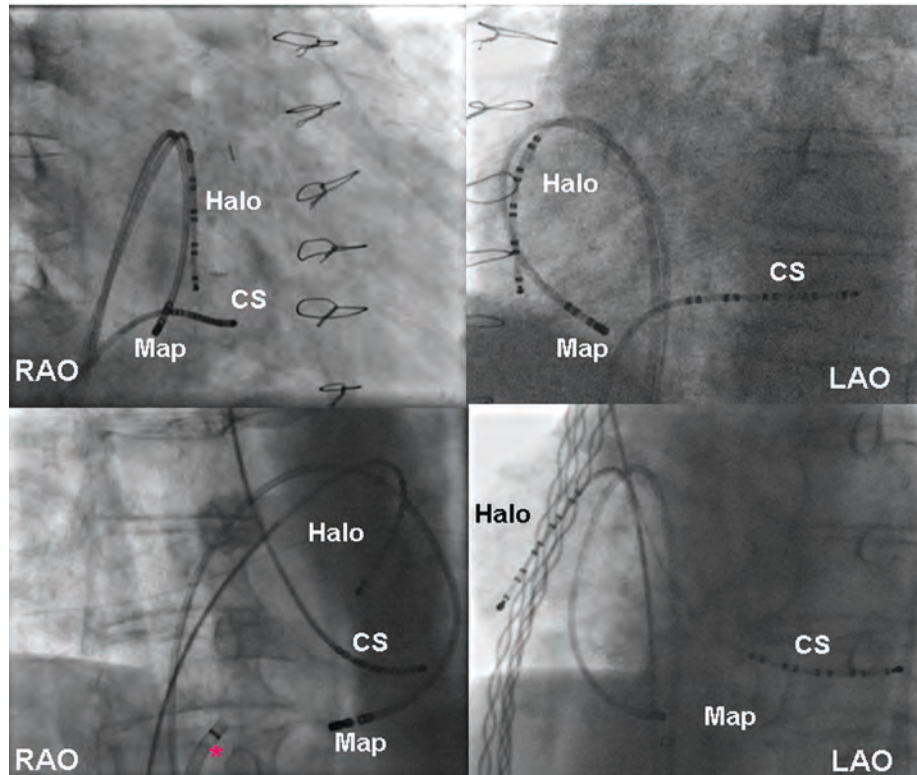


FIGURE 12.1

Example on alternative approaches to the right atrial “inferior” isthmus region for ablation of atrial flutter. These approaches allow for a different tip-tissue orientation and should be considered when the conventional “direct” approach does not succeed to achieve bidirectional block. *Upper panels* depict a large lateral loop along the free wall of the right atrium in **RAO** (*left*) and **LAO** (*right*) projection. *Lower panels* show a “transannular” approach with the ablation catheter looping in the right ventricle. This is a valuable option especially when a conduction gap at the ventricular aspect of the line is suspected.

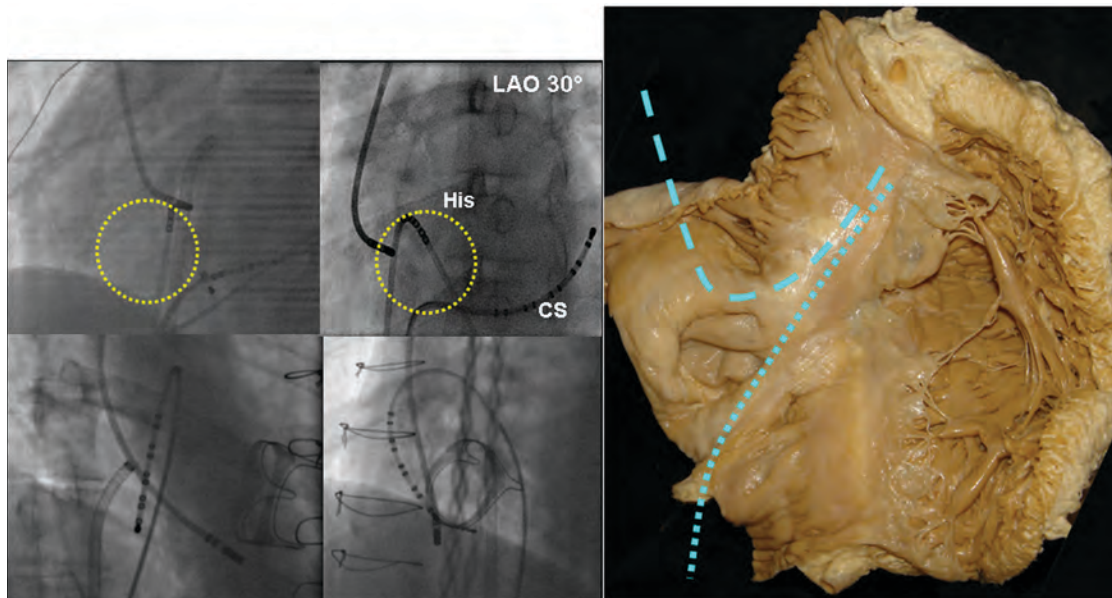


FIGURE 12.2

Stability of an ablation catheter along the tricuspid annulus can be sometimes challenging. Especially when targeting parahisian or anterolateral aspects a superior access via a jugular or subclavian sheath improves catheter tip-tissue contact and avoids easy dislodgement during ablation (*upper left panels*). The *lower left panels* show an example of an enlarged right atrium after tricuspid valve replacement where a conduction gap along the inferior isthmus is successfully closed via the superior approach (after all femoral attempts including a long guiding sheath has failed). The specimen opened through the parietal right atrioventricular junction and the parietal wall pulled away displays the septum in RAO fashion. The **broken line** indicates superior approach and the **dotted line** traces an inferior approach to the anterolateral tricuspid annulus.

Anterolateral Aspect of the Tricuspid Annulus

Stable contact around all aspects of the tricuspid annulus is occasionally difficult to achieve. A superior access via either a jugular or subclavian approach can be advantageous in this situation (Figure 12.2).