Chapter 6

Cardiac Anatomy for the Electrophysiologist with Emphasis on the Left Atrium and Pulmonary Veins

Gabriel Cismaru, Lucian Muresan, Puiu Mihai,
Radu Rosu, Gabriel Gusetu, Andrei Cismaru,
Dana Pop and Dumitru Zdrenghea

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http://dx.doi.org/10.5772/intechopen.69120

Abstract

This chapter aims to provide basic anatomical knowledge for the interventional electrophysiologists to understand catheter placement and ablation targets. We begin with the location of the heart inside the mediastinum, position of cardiac chambers, pericardial space and neighboring structures of the heart. We continue with the right atrium and important structures inside it: sinus node, cavotricuspid isthmus, Koch's triangle and interatrial septum with fossa ovalis. A special part of this chapter is dedicated to the left atrium and pulmonary veins with the venoatrial junction, important structures for catheter ablation of atrial fibrillation. We finish our description with both ventricles with outflow tracts and the coronary venous system.

Keywords: catheter ablation, cavotricuspid isthmus, anatomy, dissection, heart chambers

1. Introduction

The recent development of catheter ablation was possible, thanks to a rigorous understanding of cardiac anatomy. Appropriate cardiac structure knowledge is relevant to avoid or minimize complications during catheter placement and RF application. New strategies for pulmonary vein isolation appeared and made the procedure safety and efficient, after a meticulous characterization of the atrial muscular sleeves that prolong inside the veins.

This chapter aims to provide basic anatomical knowledge for the interventional electrophysiologists to understand catheter placement and ablation targets. We begin with the location of the heart inside the mediastinum, position of cardiac chambers, pericardial space and neighboring structures of the heart. We continue with the right atrium and important structures inside it: sinus node, cavotricuspid isthmus, Koch's triangle and interatrial septum with fossa ovalis. A special part of this chapter is dedicated to the left atrium and pulmonary veins with the venoatrial junction, important structures for catheter ablation of atrial fibrillation. We finish our description with both ventricles with outflow tracts and the coronary venous system.

2. General anatomy of the heart

The heart is positioned 2/3 to the left and 1/3 to the right of the midline of the thorax, between the two lungs. The anterior part of the heart consists of the right ventricle, which lies behind the sternum (**Figure 1**). The base of the heart lies in front of the spine. Neighboring structure is separated from the heart by the pericardium (**Figure 2**).

The posterior wall of the left atrium comes in contact with the esophagus [1], which can be close to the right or left orifices of the pulmonary veins. Catheter ablation at this level should be performed with lower energy or with temperature monitoring to avoid the risk of atrio-esophageal fistula.

On the outer surface of the pericardium [2] descend the right and left phrenic nerves. The right nerve is close to the superior vena cava and right superior pulmonary vein (RSPV) and can be damaged during cryoablation of the RSPV or RF ablation near the sinus node. In order to avoid the damage of the right phrenic nerve, high-output stimulation is performed at the level of superior vena cava and right atrium to distinguish hiccups and avoid ablation lesions at this level. The left phrenic nerve [3] is in the proximity of the left atrial appendage and can be damaged when ablating at the base of the appendage, especially in patients with persistent atrial fibrillation when extensive ablation is needed [4].

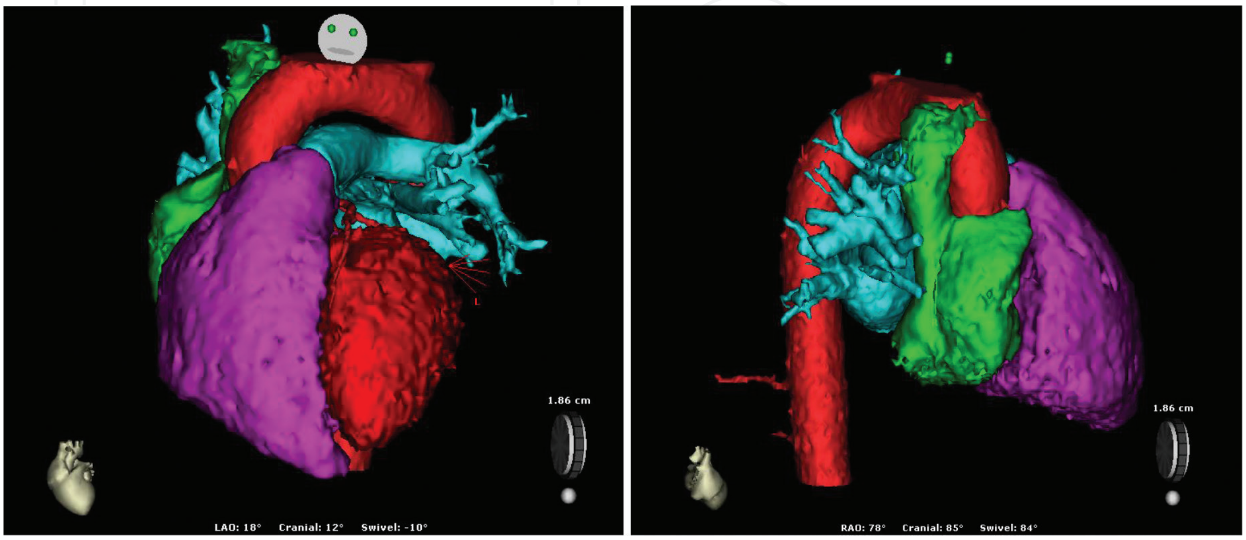

Figure 1. Heart chambers as seen in computed tomography.

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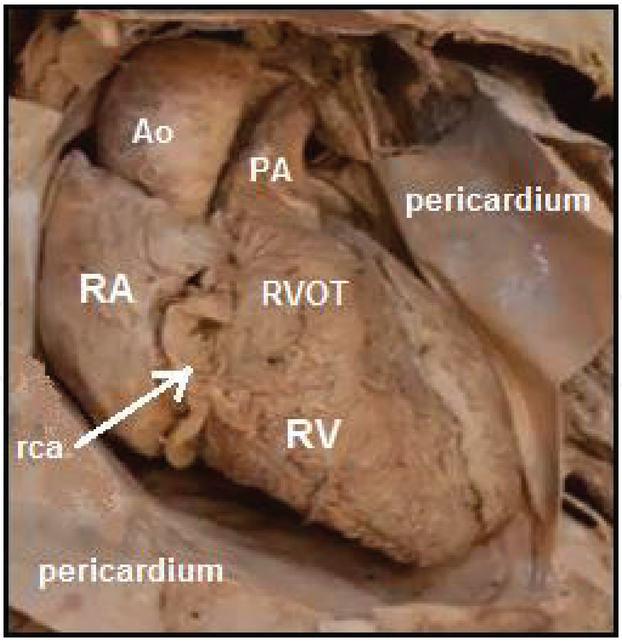

Figure 2. Parietal pericardium separating the heart from other mediastinal structures. RVOT = right ventricular outflow tract, Ao = Aorta, RA = right atrium, RV = right ventricle; rca = right coronary, PA = pulmonary artery.

3. The right atrium

The right atrium has four classical components: the vestibule, the venous part, the right atrial appendage and the interatrial septum (**Figure 3**). The sinus node is located [5] on the antero-lateral part of the right atrium, at the level of the cavoatrial junction with superior vena cava. The right atrial appendage has prominent muscular bundles that give the high amplitude potential recorded at this level with a diagnostic catheter. The vestibule surrounds the orifice of the tricuspid valve and has a smooth appearance, without pectinate muscles, present in other regions of the right atrium. The venous component lies between the superior and the inferior vena cava and forms the posterior aspect of the right atrium. It has a smooth wall that is separated from the pectinated atrial zone by the terminal crest.

The terminal part of the crest divides into small muscular bundles that form the cavotricuspid isthmus [6], an important region between the inferior vena cava and the vestibule of the tricuspid valve that is "burned" during RF ablation of typical atrial flutter. The inferior vena cava has a fibrotic partial valve that is called the Eustachian ridge, a thin flap that is an important marker for catheter ablation of atrial flutter. An important percentage of patients present pouches and recesses at the level of the cavotricuspid isthmus. These structures can make the ablation of typical atrial flutter more difficult.

The fibrotic prolongation of the Eustachian valve toward the septum is called the tendon of Todaro. With the septal leaflet of the tricuspid valve and the coronary sinus, orifice forms the triangle of Koch, an anatomical structure that every electrophysiologists should know. At this level, ablation of intranodal reentry is performed and sometimes accessory pathways can also be ablated at this level.

The interatrial septum is used to access the left atrium through transseptal puncture (**Figure 4**). The true septum that can be crossed with a transseptal needle is the fossa ovalis; at this level, the puncture is safe without the risk of pericardial bleeding.

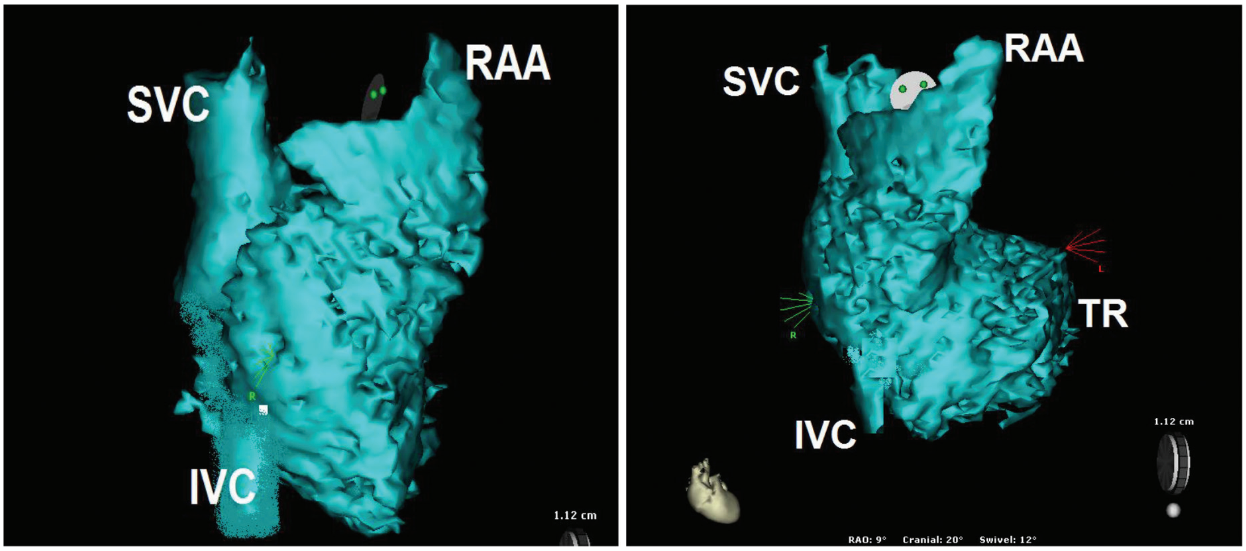

Figure 3. Computed tomography of the right atrium (the contrast substance from the cavity is subtracted and gives an image similar to an internal cast). (A) RAO view; (B) anterior view. The right atrial appendage (RAA) is an anterior structure. TR = tricuspid valve, IVC = inferior vena cava, SVC = superior vena cava.

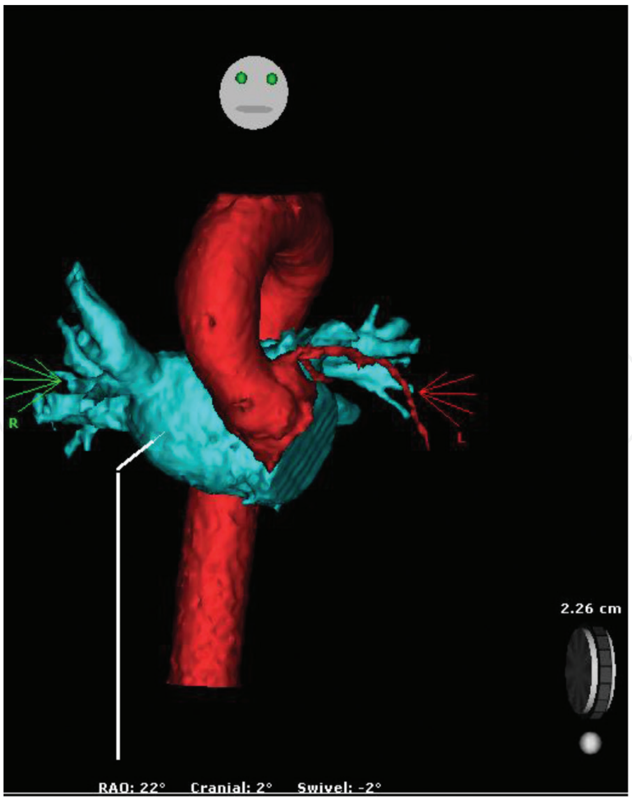

Figure 4. Position of the left atrium and ascending aorta; transseptal needle on the intratrial septum.

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When a patent foramen ovale (PFO) is present, the electrophysiologists are tented to use it as a way to the left atrium. Owing to its location, PFO directs the catheter toward the anterior and superior wall of the left atrium, making difficult the ablation of the right pulmonary veins. When using the PFO, the electrophysiologist should know that the risk of roof perforation is higher.

Catheters positioned inside the right atrium facilitates the understanding of the activation sequence in different types of arrhythmias: A Halo catheter with 20 pols positioned along the tricuspid valve records the electrical signals of counterclockwise activation in case of a typical atrial flutter; a circumferential mapping catheter placed at the base of the superior vena cava records the electrical activity when mapping sinus node reentrant tachycardia.

4. The left atrium

The left atrium is the most posterior cardiac chamber. Behind the LA lies the tracheal bifurcation, the esophagus, the descending thoracic aorta and more posteriorly the vertebral column.

The left atrium is a structure composed of four parts (**Figure 5**): the venous component that receives the pulmonary veins, the left atrial appendage, the vestibule of the mitral valve and the left interatrial septum [7]. The walls of the left atrium are anterior, superior, left lateral, septal and posterior. The interatrial septum has a 45–60 degrees angulation to the horizontal plane. The superior and posterior walls of the left atrium are smooth, whereas the left appendage presents pectinate muscles. The left atrial appendage has a particular morphology described by Biase et al.: cactus-like 30%, chicken wing 48%, windsock 19% and cauliflower 3%. Patients with chicken wing morphology are less likely to develop thrombus at this level. The left appendage is smaller than the right one [8].

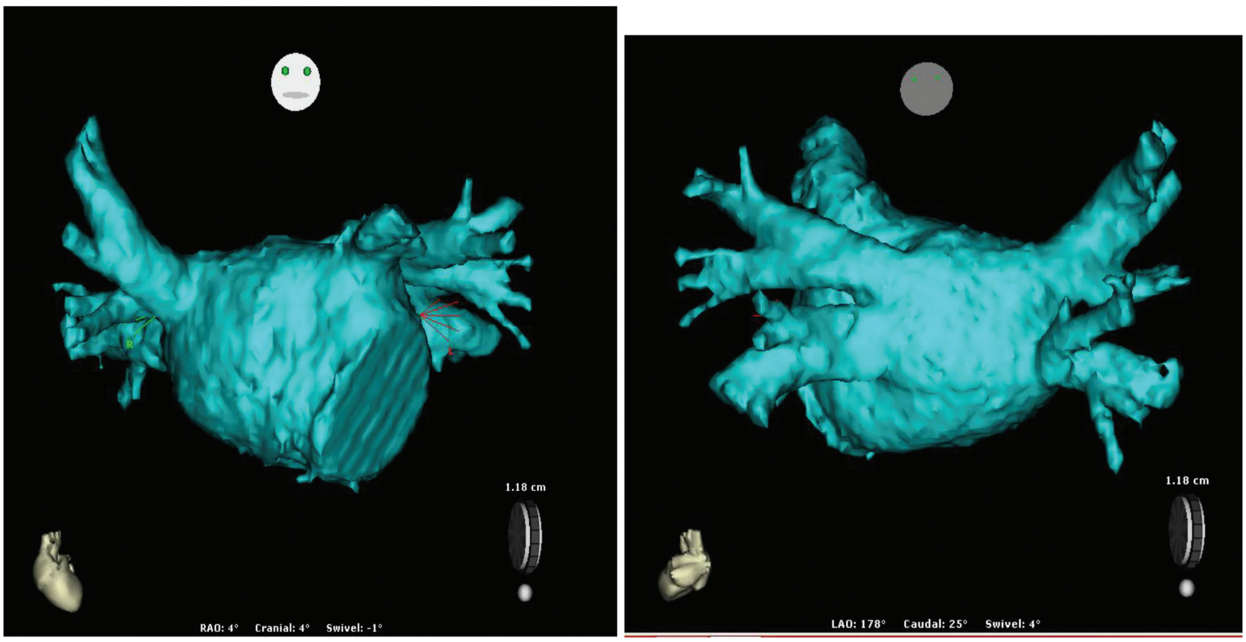

Figure 5. The left atrium with the four pulmonary veins: anterior and posterior views.

The transverse diameter of the left atrium is the largest because left atrium lies between the ascendant aorta anteriorly and the spine posteriorly and the dilation of the cavity is made between these structures. The roof of the left atrium is close to the right pulmonary artery and the bifurcation of the pulmonary trunk [9].

Between the two atrial chambers left and right, there are muscular bridges made of atrial myocardium. The most important is the Bachmann bundle, which is composed of parallel myocardial strands, extending from the left appendage to the right appendage.

Atrial fibrillation results in remodeling of the left atrium with dilation and fibrosis (the so-called atrial cardiomyopathy).

The left atrial isthmus, which is not a distinct anatomical structure, is the connecting line between the inferior margin of the LIPV and the mitral annulus. The line is used when ablating persistent atrial fibrillation and increases the success rate of the technique.

5. The pulmonary veins

The pulmonary veins drain oxygenated blood from the lungs to the posterior aspect of the left atrium. The left pulmonary veins ostia are located more superiorly than the right ostia. The right and left superior pulmonary veins are anterior and superior structures, whereas the right and inferior pulmonary veins are posterior and downwards [10]. The orifices of the veins are oval in shape with a superoinferior diameter longer than anteroposterior diameter. Usually, there are two veins on the right and two on the left side but sometimes supplementary veins can be found, more frequently on the right side. A frequent anatomical variation is the presence of a common trunk on the left side.

The musculature of the left atrium extends inside the pulmonary veins developing muscular sleeves; the longest being found in the superior veins: LSPV and RSPV. The myocardial fibers extend at a length of 1–3 cm. Usually, the sleeves are more important on the inferior part of the superior veins and on the superior part of the inferior veins.

The superior pulmonary vein is separated from the left atrial appendage by the left ridge, which is a structure that needs to be ablated during RF ablation of atrial fibrillation because muscular sleeves are very well developed at this level. The most challenging part is to obtain a good contact with the ridge.

There is a direct link between the pressure inside the pulmonary veins and abnormal electrical activations from the vein. When the left atrial pressure increases above 10 cm H2O, the junction between the LA and pulmonary veins becomes the source of abnormal activations from the pacemaker cells (Cajal-like cells).

The modern treatment of paroxysmal atrial fibrillation is pulmonary vein isolation (**Figure 6**) because ectopic triggers are found inside the pulmonary veins. Ablation of pulmonary foci is effective but with a high risk of pulmonary stenosis, therefore in the last years, ablation is performed at the level of venous antrum and aims to isolate the veins from the atrium.

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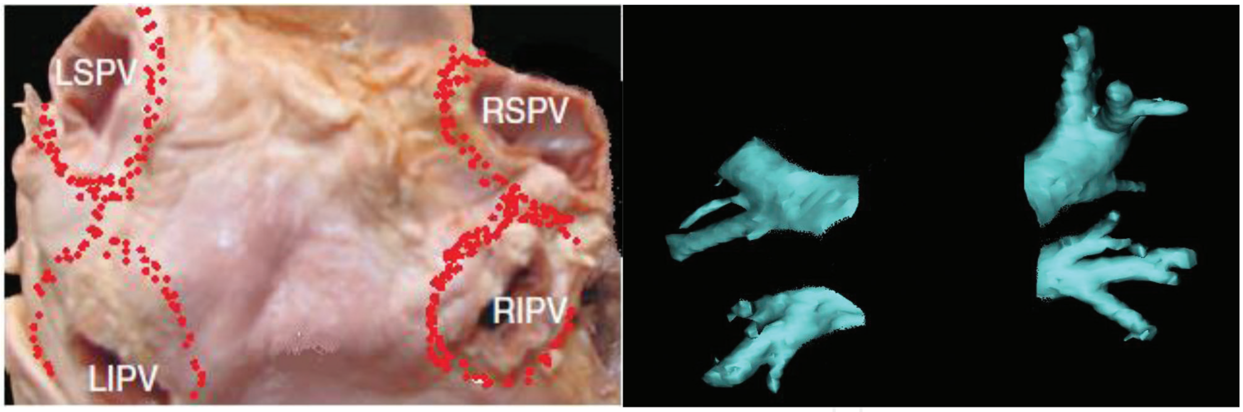

Figure 6. During catheter ablation for paroxysmal atrial fibrillation, pulmonary veins are isolated (it can be done either endocardial during electrophysiological study or epicardial during cardiac surgery).

6. The right ventricle

The right ventricle is the heart chamber that is situated the most anterior (**Figure 7**). It has three portions: the outlet or RVOT [11] that is continued with the pulmonary artery, the inlet which is delimitated by the tricuspid valve and papillary muscles, and the apical part (**Figure 8**). A thick moderator band can be present inside the right ventricle, making catheter manipulation difficult inside the RV [12].

The RVOT is superior to the left ventricular outflow tract which crosses the RVOT in a posterior position. The myocardium of RVOT is very thin, and perforations can result when a stiff tip ablation catheter is advanced directly to RVOT.

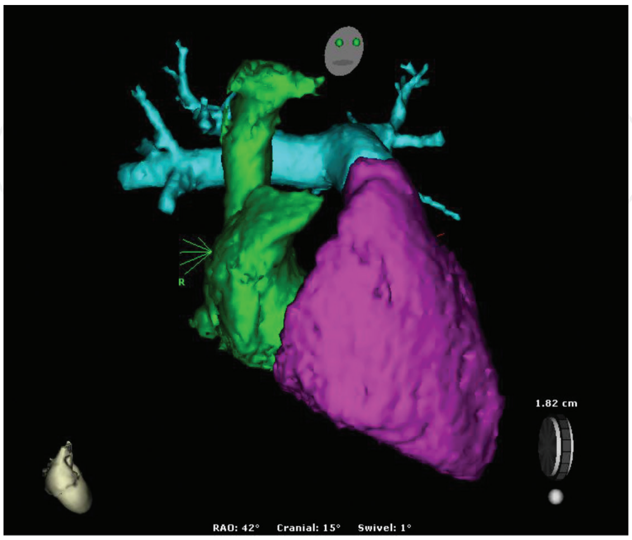

Figure 7. Right heart chambers: right ventricle, right atrium and pulmonary artery.

The RVOT is the most frequent region of benign monomorphic premature ventricular complexes. Ablation is carried at this level using pacemapping and activation mapping at the level of septal, lateral, anterior and posterior RVOT. This structure is in close relation with the left ventricular outflow tract and also aortic cusps, and sometimes mapping of these structures should be performed when ablation is not effective in the RVOT.

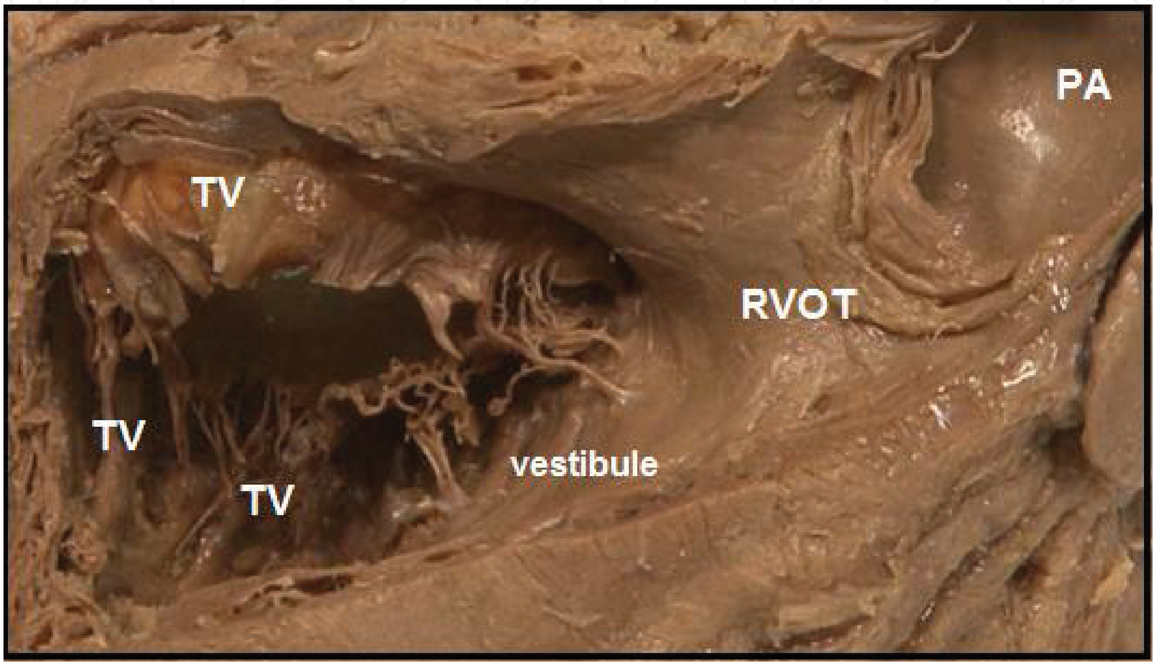

Figure 8. Inlet and outlet aspects of the right ventricle. Please note the smooth space near the tricuspid valve, which is called tricuspid valve vestibule. PA = pulmonary artery, RVOT = right ventricular outflow tract, TV = tricuspid valve.

7. The left ventricle

The left atrium is continued by the mitral valve and the left ventricle (**Figure 9**) which also has three components: inlet, outlet and apical part. The apical LV extends from the insertion of the papillary muscles to the apex. The walls of the left ventricle are thicker than those of the right ventricle but the trabeculations are finer than those of RV [13]. The anterosuperior papillary muscle and the posteroinferior papillary muscle (**Figure 10**) can be sources of ventricular premature contractions that have to be differentiated from PVC arising from the left bundle conduction system.

The LVOT is directed superiorly and anteriorly. It can be a source of ventricular premature contractions. When mapping the left ventricle, access can be achieved through the transmitral anterograde approach that requires a transseptal puncture or through the transaortic retrograde approach.

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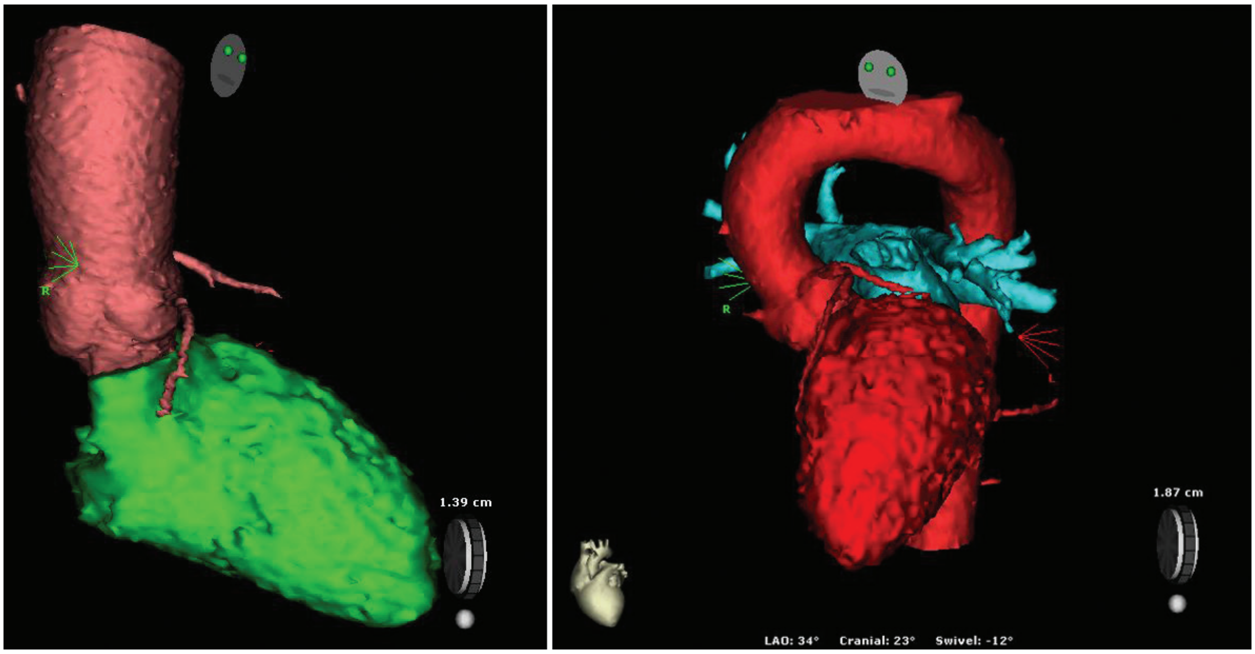

Figure 9. (A) The left ventricle with the ascendant aorta from a RAO view. (B) The left ventricle with the ascendant aorta and left atrium as seen from LAO.

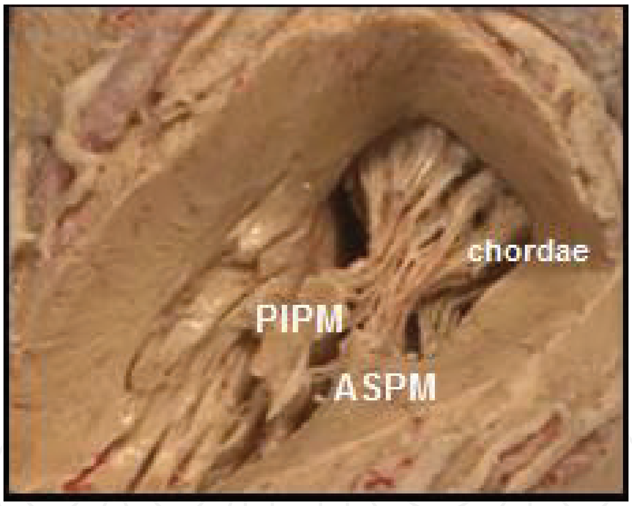

Figure 10. Anterosuperior (ASPM) and posteroinferior papillary muscles (PIPM) with chordae to the mitral valve.

8. The coronary veins

Most of the venous flow of the heart is collected by the coronary venous system. The coronary sinus drains the great cardiac vein and the middle cardiac vein as well as other small veins (**Figure 11**). The cardiac veins might be used for catheter ablation of ventricular premature contractions or ventricular tachycardias. Electrophysiologists can reach the epicardium of the left ventricle through the venous system (**Figure 12**). Small diagnostic and therapeutic (2F–5F) catheters are used inside the coronary veins, and ablation is performed usually with irrigated catheters to avoid perforation of outer walls that are not protected by muscular bundles.

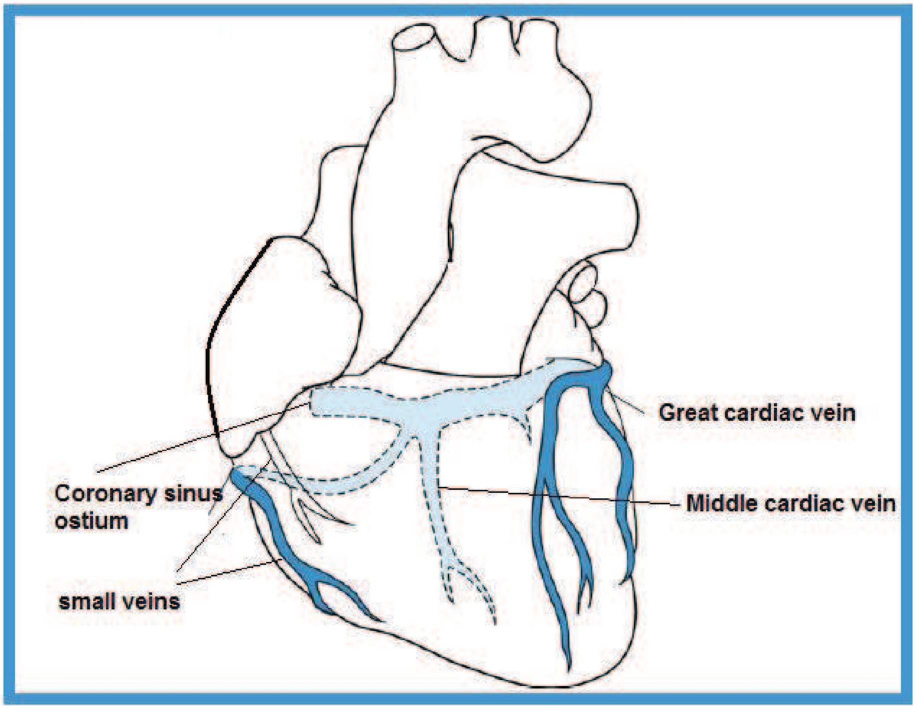

Figure 11. Coronary venous system of the heart.

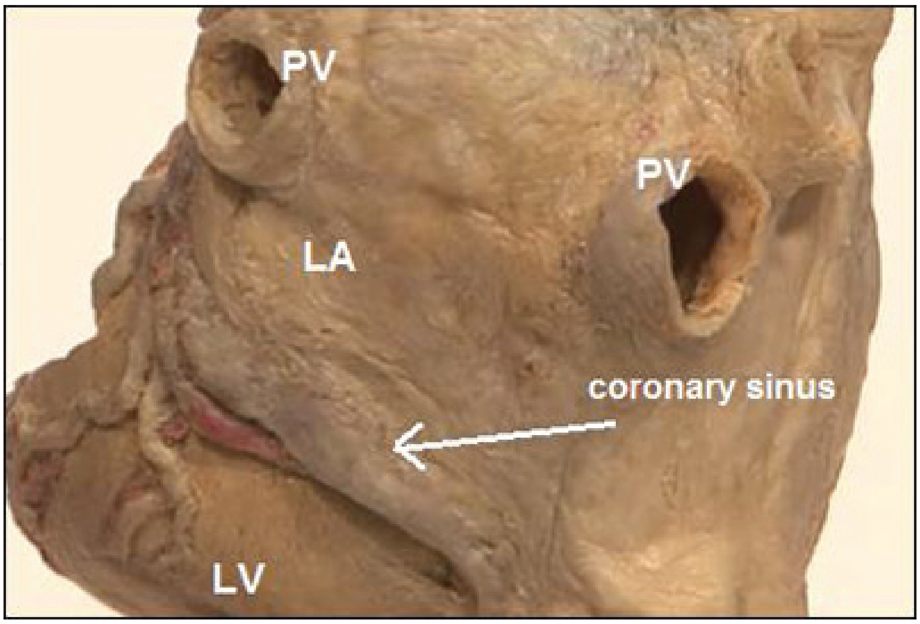

Figure 12. The coronary sinus drains venous blood from the cardiac veins. It is located between the left atrium and left ventricle. LA = left atrium, LV = left ventricle; PV = pulmonary vein.

Sometimes muscular bundles form sleeves that cover the coronary sinus and also prolong into the left atrium. These muscular bundles are target of ablation in patients with persistent atrial fibrillation that need substrate modification.

Sometimes the middle cardiac vein is dilated and forms a diverticulum of the coronary sinus. Catheter ablation might be performed at this level as posteroseptal accessory pathways could be located at this level.

The coronary sinus orifice is bordered by a small flap: the Thebesian valve that is easily passed by a diagnostic catheter because this valve is incomplete.

9. Conclusions

Our understanding of cardiac anatomy has grown exponentially in the era of catheter ablation. The knowledge of the anatomy of a specific cardiac chamber and its relationship with neighboring structures is relevant for interventional electrophysiologists when mapping and ablating different arrhythmias.

Each cardiac structure can be a source of arrhythmias, and the knowledge of the particular anatomy facilitates the understanding of the mechanism behind the abnormal rhythm and how it can be controlled. Safe ablation comes not only from an improved understanding of the gross cardiac anatomy but also from a good awareness of the histological characteristics and architectural microstructure.

Acknowledgements

The research was supported by the internal grant of the University of Medicine and Pharmacy Iuliu Hatieganu Cluj-Napoca No 4994/1/08.03.2016.

Author details

Gabriel Cismaru[1]*, Lucian Muresan[1], Puiu Mihai[1], Radu Rosu[1], Gabriel Gusetu[1], Andrei Cismaru[2], Dana Pop[1] and Dumitru Zdrenghea[1]

*Address all correspondence to: gabi_cismaru@yahoo.com

1 5th Internal Medicine Department, Cardiology-Rehabilitation, Iuliu Hatieganu University of Medicine and Pharmacy, Cluj-Napoca, Romania

2 11th Oncology Department, Oncology, Iuliu Hatieganu University of Medicine and Pharmacy, Cluj-Napoca, Romania

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