Anatomic insights for catheter ablation of ventricular tachycardia

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Safe maneuvering of catheters in and around the ventricles, and ablations for ventricular tachycardia, require knowledge of the anatomy of the cardiac and extracardiac structures. This review emphasises the three-dimensional spatial relationships between the right and left ventricles and highlights the important extracardiac structures in the vicinity of the ventricles. The spatial relationships between the right and left ventricles are intricate owing to the curvature of the ventricular septum. The crossover relationship between the right and left ventricular outflow tracts and different planes and angulations between the aortic and the pulmonary valves is particularly relevant to intervening in the ventricular outlets. Importantly, the central location of the aortic valve in the heart puts it in the vicinity of all four cardiac chambers, both for access and for reducing risk of damage to vital structures such as the atrioventricular conduction bundle. The locations of the cardiac chambers are not as simple as implied by the commonly used terms 'right heart' and 'left heart'.

KEYWORDS Anatomy; Conduction system; Ventricles; Catheter ablation

(Heart Rhythm 2009;6:S77–S80)

Introduction

Whatever the substrate for ventricular tachycardia, knowledge of cardiac anatomy is important when maneuvering catheters in and around the ventricular chambers in order to reduce the potential for procedural complications. This review highlights some relevant spatial relationships between chambers in the structurally normal heart, the morphology of the right and left ventricles, and the anatomy relevant to epicardial approach. No attempt is made to review all aspects of cardiac anatomy or distortions resulting from pathologic changes.

Disposition of the cardiac chambers

The terms *right heart* and *left heart* commonly used in clinical practice obfuscate the true disposition of the cardiac chambers.[1] The availability of imaging tools to visualize the heart *in situ* together with three-dimensional reconstructions helps greatly in demystifying some of the intricacies of gross cardiac anatomy, allowing better appreciation of the spatial relationships between chambers, valves, and the orientations of the atrial and ventricular septal structures.[2] The plane of the cardiac septum at an angle of approximately 45° to the median plane places the right atrium and right ventricle anterior to their respective left counterparts rather than side by side, and the atria are posterior relative to their ventricles.[3] In addition, the ventricular septum is not straight but curves such that the left ventricle appears circular in cross-section and "wrapped" by the crescentic right ventricle. Particularly relevant to ventricular tachycardia ablation is understanding the "crossover" relationship between the right and left ventricular outflow tracts. The right ventricular outlet passes cephalad in a posterior and slightly leftward direction. In some hearts, the tip of the left atrial appendage may overlie the left anterior wall of the pulmonary trunk or outflow tract. The left ventricular outlet passes underneath the right ventricular outlet in a rightward and cephalad direction pointing toward the right shoulder (Figure 1a). Furthermore, the pulmonary and aortic valves are not at the same level. The pulmonary valve, the most superiorly situated of the cardiac valves, lies at the level corresponding to the third left costal cartilage at its junction with the sternum. The transverse plane of the aortic valve slopes inferiorly, away from the plane of the pulmonary valve, such that the orifice of the aortic valve faces rightward at an angle of at least 45° from the median plane.[4] Not only that, the difference in levels between the two sets of arterial valves may be exaggerated by the length of the freestanding cone of muscle supporting the pulmonary valve known as the subpulmonary infundibulum (see below). In between the aortic valve and the infundibulum is an epicardial tissue plane, not a part of the ventricular septum.

The key to cardiac anatomy is the central location of the aortic root (Figure 1). Anterosuperior to the root lies the pulmonary valve and subpulmonary infundibulum. Owing to the offset in levels between aortic and pulmonary valves, the aortic sinuses closest to the pulmonary valve in fact lie behind the subpulmonary infundibulum. These are the aortic sinuses that give origin to the main right and left coronary arteries. As these main coronary arteries descend toward their respective atrioventricular

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1547-5271/$ -see front matter doi:10.1016/j.hrthm.2009.02.008

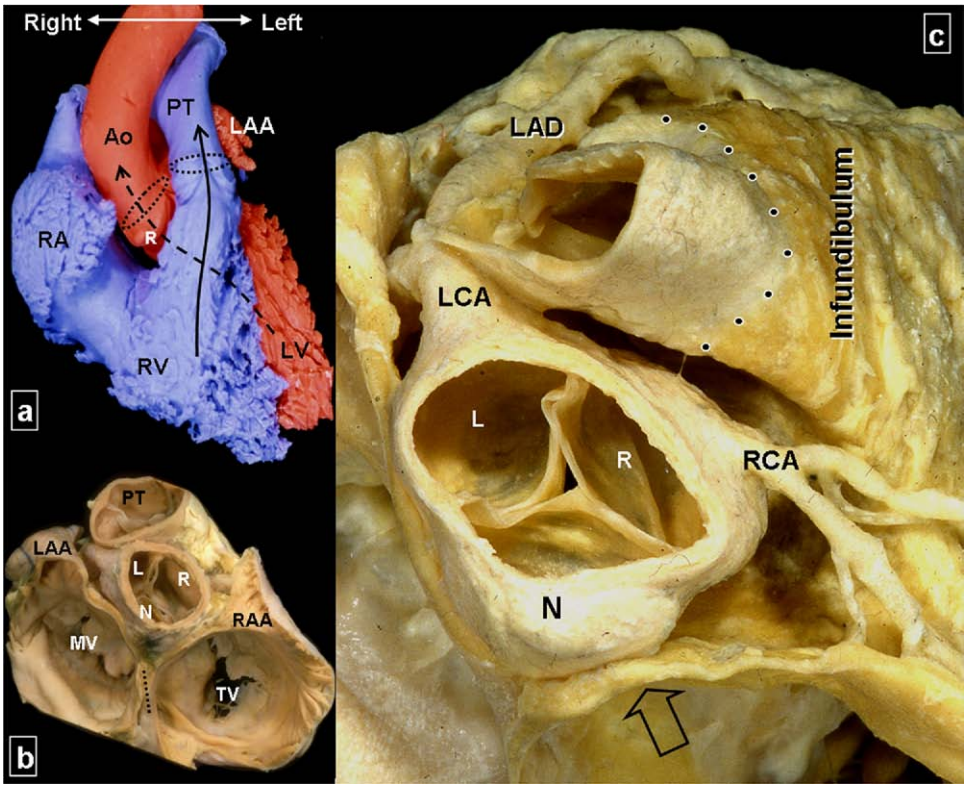

Figure 1 **a:** Endocast of a normal heart viewed from the front showing the crossover relationship between right and left ventricular outflow tracts *(arrows)*. *Dotted ovals* represent the orifices of the pulmonary and aortic valves. **b:** Atrial chamber transected and pulmonary and aortic valves cut at the level of the sinutubular junctions. The heart viewed from the right and posterior shows the central location of the aortic valve. Note the near alignment between a closure line of the aortic valve with that of the tricuspid valve. *Dotted line* represents plane of the atrial septum. **c:** Epicardial fat removed to show the ventriculoarterial junction *(dotted line)* between the pulmonary sinuses and the infundibulum and the relationship between the infundibulum and the aortic sinuses. *Open arrow* indicates the aortic mound in the right atrium. Ao = aorta; L = left coronary aortic sinus; LAA = left atrial appendage; LCA = left coronary artery; LAD = left anterior descending artery; LV = left ventricle; MV = mitral valve; N = noncoronary aortic sinus; PT = pulmonary trunk; R = right coronary aortic sinus; RA = right atrium; RAA = right atrial appendage; RCA = right coronary artery; RV = right ventricle; TV = tricuspid valve.

grooves, they pass within millimeters of the epicardial aspect of the infundibulum (Figure 1).[5] The posteroinferior wall of the infundibulum is related to the bulging coronary sinuses of the aortic root. The third aortic sinus, the noncoronary sinus, bulges toward the plane of the atrial septum. Thus, the posteroinferior margin of the aortic root is flanked by atrial walls. In turn, the bulge of the sinus causes an eminence in the right atrial wall known as the "aortic mound" or "torus aorticus," not to be mistaken for the atrial septum, which lies more posteroinferiorly (Figures 1b and 1c). Another important relationship is the near alignment of the closure line between the right and the noncoronary aortic leaflets with the closure line between the septal and anterosuperior leaflets of the tricuspid valve (Figure 1b). The two valves are separated by the membranous septum at the central fibrous body. From the atrioventricular node, the His bundle penetrates through the central fibrous body to emerge as the atrioventricular conduction bundle on the left side, sandwiched between the membranous septum and the crest of the ventricular septum. As a result of this close relationship, focal atrial tachycardia near the His bundle may be targeted from the aortic sinuses.[6]

Right ventricle and outflow tract

The orifice of the tricuspid valve marking the inlet to the right ventricle is oriented nearer to the vertical plane than the horizontal plane. A muscular fold representing the inner curvature of the primitive heart tube separates the tricuspid from pulmonary valves (Figure 2a). This fold, the ventriculo-infundibular fold, inserts into the top of the ventricular septum forming the supraventricular crest. It continues into the subpulmonary infundibulum without any anatomic demarcation between the two structures. The infundibulum is the term given to the conical-shaped right ventricular outflow tract that adjoins the arterial wall of the pulmonary trunk at the ventriculoarterial junction (Figures 2a and 2b). Thus, its wall thickness tapers from the regular 3 to 5mm at the ventricular body to 1 to 2 mm at the junction. The pulmonary sinuses are not as prominent as the aortic sinuses. Nevertheless, owing to the semilunar configuration of the valvar leaflets, the hinge line of each leaflet crosses the ventriculoarterial junction at two points. Consequently, there are always small segments of myocardium of the infundibulum at the nadirs of the three sinuses (Figure 2b). Between adjacent sinuses, the wall comprises small trian-