Recent decades have seen rapid developments in arrhythmia treatment, especially the use of catheter ablation. Although the substrates of atrial fibrillation, its initiation and maintenance, remain to be fully elucidated, catheter ablation in the left atrium has become a therapeutic option for patients with this arrhythmia. With ablation techniques, various isolation lines and focal targets are deployed; the majority of these are anatomic approaches. It has been over a decade since we published our first article on the anatomy of the left atrium relevant to interventional electrophysiologists.1 Our aim then, as now, was to increase awareness of anatomic structures inside the left atrium. In this review of anatomy, we revisit the left atrium, inside as well as outside, for a better understanding of the atrial component parts and the spatial relationships of specific structures.

Location and Atrial Walls

Viewed from the frontal aspect of the chest, the left atrium is the most posteriorly situated of the cardiac chambers. Owing to the obliquity of the plane of the atrial septum and the different levels of the orifices of the mitral and tricuspid valves, the left atrial chamber is more posteriorly and superiorly situated relative to the right atrial chamber. The pulmonary veins enter the posterior part of the left atrium with the left veins located more superior than the right veins. The transverse pericardial sinus lies anterior to the left atrium, and in front of the sinus is the root of the aorta. The tracheal bifurcation, the esophagus, and descending thoracic aorta are immediately behind the pericardium overlying the posterior wall of the left atrium. Further behind is the vertebral column.

Following the direction of blood flow, the atrial chamber begins at the pulmonary veno-atrial junctions and terminates at the fibro-fatty tissue plane that marks the atrioventricular junction at the mitral orifice. The walls of the left atrium are muscular and can be described as superior, posterior, left lateral, septal (or medial), and anterior, as suggested by McAlpine,2 who drew attention to the importance of describing the heart in its anatomic position in the chest, in the orientation he termed “attitudinal,” which is the appropriate terminology for cardiac interventionalists.3 The left atrium is relatively smooth-walled on its internal aspect (Figure 1A), but its walls are not uniform in thickness. The roof or superior wall is in close proximity to the bifurcation of the pulmonary trunk and the right pulmonary artery. The thickness of its muscle component measured transmurally ranges from 3.5 to 6.5 mm (mean, 4.5±0.6 mm) in formalin-fixed heart specimens.4 The thickness of the lateral wall ranges between 2.5 and 4.9 mm (mean, 3.9±0.7 mm). The anterior wall, related to the aortic root, ranges from 1.5 to 4.8 mm (mean, 3.3±1.2 mm) thick, but it can become very thin at the area near the vestibule (Figure 1B) of the mitral annulus, diminishing to an average thickness of 2 mm. Importantly, there is an area of the anterior wall just behind the aorta that is exceptionally thin, an area noted by McAlpine as the “unprotected” area at risk of perforation. The posterior wall of the left atrium, including its inferior part, is related to the esophagus and its nerves (vagal nerves), the thoracic aorta, and the coronary sinus (Figure 1C). Its mean thickness is 4.1±0.7 mm (range, 2.5–5.3 mm) which tends to become thinner toward the orifices of the left and right pulmonary veins.1 Postmortem measurements of the midportions transmurally revealed the area between the superior pulmonary veins to be the thinnest, 2.3±0.9 mm, with no significant difference between patients with and without atrial fibrillation, whereas the wall was thinner in the middle and between the inferior venous orifices in those with atrial fibrillation.5

The coronary sinus, with its continuation, the great cardiac vein, runs along the epicardial aspect of the posteroinferior region (Figure 2A). The venous structure is covered by fatty tissues of the left atrioventricular groove, but in the majority of hearts it is not at the same level as the mitral annulus.6 When viewed from the anterior aspect of the chest, the coronary sinus runs superior to inferior, whereas when viewed from a left and anterior perspective, the venous channel runs from posterosuperior to anteroinferior. During cardiac development, the oblique vein of the left atrium (vein of Marshall) passes from a superior aspect onto the epicardial surface of the left atrium in between the left atrial appendage and the left superior pulmonary vein to descend along the posterolateral atrial wall to join the coronary sinus (Figure 2B). This is at the junction of the sinus with the great cardiac vein, which is usually marked by a set of flimsy valves known as the valve of Vieussens (Figure 2C). In some individuals,
the lumen of the oblique vein remains patent, forming the persistent left superior caval vein, draining into the coronary sinus. In the majority of individuals, however, this vein becomes a fibrous strand, the ligament of Marshall. Kim et al demonstrated multiple myocardial “tracts” present within the vein/ligament that insert directly into the coronary sinus musculature or into the posterior free wall of the left atrium.7 The coronary sinus is wrapped by its own muscular coats to varying extents from near the insertion of the Marshall vein/ligament to its opening in the right atrium. The sleeve covers a length of 25–52 mm and increases in thickness toward the coronary sinus orifice.8 Muscular continuity between venous walls and the posterior and inferior left atrial wall is common.1,8,9 The free wall of the coronary sinus, however, is often thin and relatively unprotected.

**Pulmonary Veins**

Our anatomic study on a series of 35 heart specimens found the classic arrangement of 4 orifices in 74%, with 31% of these in the setting of a short vestibule or funnel-like common vein. Five venous orifices were found in 17%, and the remaining 9% had a common vein on the left or right side.10 In the classic pattern, the right superior pulmonary vein passes behind the junction between the right atrium and the superior caval vein, whereas the inferior pulmonary vein passes behind the intercaval area (Figure 3A). The orifices of the right pulmonary veins are directly adjacent to the plane of the atrial septum. Improvements in imaging techniques over the past decade have revealed considerably more variations in the number of venous orifices and their arrangements.11,12

Sleeves of muscle extend from the left atrium to surround the outer aspects of the venous walls for markedly varying lengths toward the lung hilum (Figure 3A and 3B).13,14 These sleeves are well illustrated in the publication by Keith and Flack (1907) that documented their discovery of the sinus node.15 Although electric activity in this region has long been recognized,16,17 it is only in the recent era that muscular sleeves have come under scrutiny among cardiac electrophysiologists, owing to their association with focal activity initiating atrial arrhythmias.18,19 The muscle sleeves are thickest at the veno-atrial junction (1–1.5 mm), and it then fades away toward the lungs. Despite the term veno-atrial junction, the structural border between vein and atrium is indistinct because it has characteristics of both its neighbors (Figure 3C). The endocardium of the left atrium continues

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[Figure 1. A] Dissection through the atria with parts of the anterior walls removed and viewed from a left anterior perspective to show the components of the left atrium and its relatively smooth endocardial surface. B, This dissection of the atria viewed from the back shows the close relationship of the aortic root to the atria, including the atrial septum. C, This specimen viewed from the left shows the posterior location of the left atrium and its relationship to cardiac and extracardiac structures. Asterisk marks the location of the coronary sinus. Eso indicates esophagus; LAA, left atrial appendage; Li, left inferior; LS, left superior; PV, pulmonary vein; Ri, right inferior; RS, right superior; RAA, right atrial appendage; and Tr, trachea.

[Figure 2. A] Heart sectioned and viewed from simulated left anterior perspective to show the course of the coronary sinus (CS) relative to the left atrium (LA). The area of fibrous continuity between aortic and mitral valves lies between the open triangles. B, This dissection shows the inferior aspect of the heart with the epicardium of the left atrium and left ventricle removed. The insertion of the ligament of Marshall (LoM) marks the junction between great cardiac vein (gcv) and the coronary sinus. Note the musculature around the CS and LoM compared with the mainly bare wall (pale color) of the gcv. C, This histological section in a similar plane to the heart in A is stained in Masson trichrome stain, which displays muscle as red and fibrous tissue as green. The CS has a muscular sleeve and is separated from left atrial wall by a narrow space (**) that may be traversed by myocardial strands. ICV indicates inferior caval vein.
patchy fibrosis is commonly seen. The left atrium has a distinctive appendage that is a finger-like pouch extending from the main body of the atrium. The main body then comprises of the pulmonary venous portion, like a pouch extending from the main body of the atrium. The right inferior pulmonary vein (RI) passes behind the right superior pulmonary vein (RS) to the left atrial appendage (LAA), and it has a longer perspective than the left inferior pulmonary vein (LI). The epicardium has been removed from this heart. This view from the back shows the “classic” pattern of 4 pulmonary veins entering the left atrium and the relationship of the junction between the superior caval vein (SCV) and the right atrium. The right inferior pulmonary vein (RI) passes behind the intercaval area. Note the sleeves of atrial muscle continuing around the pulmonary veins and the SCV. Bare venous walls appear pale in color. B. This view from the left and posterior perspective shows the proximities of the left superior pulmonary vein (LS) to the left atrial appendage (LAA), and it has a longer muscle sleeve than the left inferior pulmonary vein (LI). C. Removal of the posterior wall of the left atrium shows the entrances of the pulmonary veins without discrete veno-atrial junctions. D. This histological section in Masson trichrome stain shows the thinner atrial wall becoming thinner at the entrances of the veins to form the muscular sleeves, which taper toward the lungs. Note the interpulmonary “ridge” (arrow) and the epicardial fibro-fatty tissues (*) containing abundant nerve bundles. ICV indicates inferior caval vein.

The septal portion, and the vestibule, which is the outlet part of the atrial chamber surrounding the mitral orifice. Apart from the appendage, which has a fairly well-defined opening (the os to the appendage), the other component parts do not have clear anatomic demarcations.

**The Appendage**

The left atrial appendage is considerably smaller than its counterpart on the right side. It tends to have a small, narrow, tubular shape with several bends (Figure 4A). A study of postmortem and explanted hearts revealed the atrial appendage from patients with atrial fibrillation to have 3 times the volume of those in sinus rhythm. These investigators also reported that the endocardial surface was smoother and associated with more extensive endocardial fibroelastosis in those with atrial fibrillation and that these features could predispose to thrombus formation. The tip of the appendage points anterior and cephalad in most cases and overlaps the base of the pulmonary trunk, the left coronary artery, or its anterior descending branch and the great cardiac vein at varying levels. In others, the tip can be directed inferior, posterior, or infrequently, into the transverse pericardial sinus. Externally, the appendage shows multiple crenellations, giving wide variations in number and arrangement of lobes or branches. Its endocardial aspect is lined with muscle bundles of varied thicknesses arranged in whorl-like fashion. The wall of the appendage is paper-thin between the muscle bundles. Unlike the right atrium, the left atrium lacks a terminal crest. Instead, the border between appendage and body of the left atrium is the oval-shaped os, with a mean long diameter of 17.4 ± 4 mm and short diameter of 10.9 ± 4.2 mm measured on heart specimens.

Our studies of the muscular sleeves have shown mainly circularly arranged myocardial strands that are pierced with interdigitating longitudinally and obliquely orientated bundles in the sleeves. As the myocardial sleeves thin out, patchy fibrosis is commonly seen.**

**Structure of the Left Atrium**

The left atrium has a distinctive appendage that is a finger-like pouch extending from the main body of the atrium. The main body then comprises of the pulmonary venous portion, the septal portion, and the vestibule, which is the outlet part of the atrial chamber surrounding the mitral orifice. Apart from the appendage, which has a fairly well-defined opening (the os to the appendage), the other component parts do not have clear anatomic demarcations.

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In some hearts, the endocardial aspect of the atrial body around the os can be associated with pits and troughs where the wall becomes remarkably thin (Figure 4B).

**Septal Component**

The anterior part of the septal component is closely related to the aortic root through the transverse pericardial sinus. Structurally, this component is more complex than it appears at first glance. When viewed from the cavity of the left atrium, the septal component merges into the roof, the posterior wall, and the vestibule. There is little to distinguish the true atrial septum from...
is the true septum.

This longitudinal cut through the 4 cardiac chambers shows the atrial septum in profile. The floor of the oval fossa (open arrow) is the true septum. Asterisks mark the levels of attachments of the tricuspid and mitral valves at the septum. The inferior pyramidal space (small arrow) is covered by the vestibule of the right atrium. C, This histological section taken through the short axis of the heart shows the thin flap valve (open arrow) and the muscular rim of the fossa (small arrows). Note the uneven thickness of the left atrial wall. D, This view of the septal component shows a patent foramen ovale (open arrow). Its opening is behind the anterior wall of the left atrium and the transverse pericardial sinus. CS indicates coronary sinus; ICV, inferior caval vein; SCV, superior caval vein; LI, left inferior; LS, left superior; P, pulmonary vein; RI, right inferior; and RS, right superior pulmonary veins.

its surroundings. A small crescent-like edge is usually the only discernable margin of the flap valve of the oval fossa (or floor of the fossa) that is developed from the embryonic septum primum (Figure 5A). The rest of the flap valve blends into the paraseptal atrial wall. Thus, the extensive fossa valve overlaps the embryonic septum secundum, which is represented by the raised muscular rim (or limbus) that is situated on the right atrial side of the septal component (Figure 5B). During fetal life, the fossa valve allows blood to flow from the right atrium to the left atrium through the oval foramen (ostium secundum). After birth, the fossa valve completely adheres to the left atrial margin of the rim in most hearts, sealing the fossa opening. A recent study that examined the septal aspect in 94 heart specimens reported finding a septal pouch in nearly 40%, which is due to inadequate fusion of the overlapping septum primum to the septum secundum despite having obliterated the oval foramen.27 An inadequate fusion along the caudal part of the overlap at the foramen results in a pouch on the left atrial side (see online-only Data Supplement), whereas fusion limited to the cephalad part of the overlap results in a pouch on the right atrial side. The pouches may become sites for thrombus deposits.27 However, persistent patency at the foramen, a patent foramen ovale (PFO) is present in 10–35% of the population.28 This is the residual free margin of the fossa valve that is visible as the crescent-like edge on the endocardial surface of the left atrium.

Appreciating that the muscular rim is an infolding of the atrial wall is relevant to defining the site of the true septum that should be the target area for the transeptal puncture.29 It is the thin floor of the fossa, measuring approximately 1–3 mm in thickness in normal hearts that allows direct access between the atrial chambers. It comprises a bilaminar arrangement of myocytes with variable amounts of fibrous tissue.30,31 The location and size of the oval fossa varies from case to case, as does the profile or prominence of the muscular rim.32 Furthermore, abnormalities of the thorax or of the cardiovascular system such as kyphoscoliosis or marked left ventricular hypertrophy may result in displacement of the fossa ovalis.33 Cases with patches, occluder devices, aneurysmal valves of the oval fossa, and thickly fibrosed septum that may be due to previous transeptal procedures are particularly challenging to perforate. The aneurysmal fossa valve is detected as a saccular excursion of >1 cm away from the plane of the atrial septum. In these hearts, the fossa membrane often is thinner, devoid of muscle cells, and mainly composed of connective tissue, making it more resistant to being perforated and yet more likely to be “tented” deep into the left atrial cavity with the risk of reaching the lateral wall. Approximately one-third of hearts with aneurysmal fossa are associated with a PFO. With or without aneurysmal configuration, the PFO is situated at the antero-cephalad margin of the fossa. In heart specimens, the PFO ranges from 1 to 10 mm in diameter, and the length of the tunnel depends on the extent of overlap between the flap valve and the rim.34 The location, size, and tunnel-like form of the PFO should be considered if it is to be used as a portal for transeptal crossing because they can affect ease of catheter movement and access to reach target areas such as the right inferior pulmonary vein. Importantly, the crescentic aperture of the PFO opens immediately behind the anterior wall of the left atrium (Figure 5D).

Because the interatrial groove (also known as the Waterston groove to the cardiac surgeons) marks the epicardial aspect of the infolded muscle rim, it is not a true septal structure. It can become quite thick, especially in its superior, posterior, and inferior margins. In some patients, the epicardial fat may increase the thickness of the infolding to 1–2 cm in the normal heart. Thickness of more than 2 cm on noninvasive imaging is increasingly reported as indicative of lipomatous hypertrophy, with incidence up to 8%. On cross-sectional echocardiography, the septum appears like a “dumbbell.”35 Even in hearts without so-called “septal hypertrophy,” transgression through the rim can hinder needle penetration, and, being a thicker structure, can restrict maneuverability after crossing and also increase the risk of exiting the heart, dissecting into the fatty tissue plane, and causing hemopericardium. At particular risk is the anterior rim of the fossa, which is in close anatomic relationship with the aortic mound. The latter is seen as a protuberance into the right atrial cavity. Puncture in this area is likely to allow the needle to enter the transverse pericardial sinus, resulting in a high risk of aortic perforation. Notably, it is not uncommon to find small pits and crevices in this region that may lodge the tip of a perforating
respectively.\textsuperscript{37} The subendocardial strands at the veno-atrial junctions are mainly loop-like extensions of the longitudinal and oblique strands from the atrial wall. Abrupt changes in orientation of the strands in the subendocardium may be observed in the interpulmonary areas, where obliquely or circumferentially aligned myocardial strands meet with predominantly longitudinally aligned strands (Figure 6A and 6B). Usually the area of abrupt change is accompanied by a change in wall thickness, thicker toward the septum and thinner laterally.

Viewed from within the atrial cavity, the endocardial surface has the appearance of ridges in between the superior and inferior venous orifices. In addition, there is a ridge-like structure between the entrance of the left superior pulmonary vein and the os of the left atrial appendage. The interpulmonary carinae (or isthmuses) may have transmural myocardial thicknesses up to 3.2 mm. Intervenous muscular connections are commonly located toward the epicardial surface (Figure 6C).\textsuperscript{38} These cross from the anterior quadrant of the superior venous sleeve to the posterior quadrant of the inferior venous sleeve and vice versa (Figure 6D). Direct connections between superior and inferior venous sleeves are also common.

The left lateral “ridge” between the appendage and the left pulmonary veins was first described by Keith in 1907 as the “left tenia terminalis.”\textsuperscript{39} It is recognized as a Q-tip sign on echocardiographic imaging and, when prominent, can be mistaken for a thrombus or atrial mass. Integral to the ablation line for isolating left pulmonary veins, this “ridge” is actually an infolding of the lateral atrial wall. The fold is narrower at its superior border with the left superior pulmonary vein compared with its border with the inferior pulmonary vein (2.2–6.3 mm versus 6.2–12.3 mm). In 75\% of the hearts studied, the fold is less than 5 mm wide and its profile of the fold varies from being flat, round, or pointed (Figure 7A and 7B). The fold has thicker muscle in the anterosuperior portion. Within the fold runs the remnant of the vein of Marshall, abundant autonomic nerve bundles, and a small atrial artery which, in some cases, is the sinus nodal artery (Figure 7C).\textsuperscript{7,40} A study on postmortem hearts revealed that the Marshall remnant is less than 3 mm from the endocardial surface and that the fold has muscular connections to the pulmonary veins.\textsuperscript{40}

The Vestibule and the Mitral Isthmus

Surrounding the outlet of the atrium is the vestibule. On the endocardial aspect, it is a smooth zone. The myocardium of its distal parts overlaps the atrial surfaces of the mitral leaflets to a greater or lesser extent, albeit only for a millimeter or so. Owing to the left ventricular outflow tract interposing between the ventricular septum and the mitral valve, the portion of the vestibule overlying the area of normal fibrous continuity between the mitral and aortic valves is distant from ventricular myocardium (Figure 2A). Although the remaining part is close to the ventricular myocardium, fibro-fatty tissues at the mitral hinge line (annulus) serve as an insulating plane between atrial and ventricular masses. For normal conduction of the cardiac impulse from atria to ventricles, it is well recognized that there

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**Figure 6.** A, This is a view of the roof and posterior wall of the left atrium with transillumination to demonstrate the thinner parts of the walls. The epicardium has been removed to show the arrangement of the myocardial strands (broken arrows) in the superficial parts of the walls. B, This view of the posterior and inferior walls shows abrupt changes in orientation of the myocardial strands (broken arrows). An interatrial muscle bundle is present in this heart (double-headed arrow). C, This view of the lateral left side shows the myocardial strands in the region between the left superior (LS) and left inferior (LI) pulmonary veins (arrow). D, Muscle bridges (arrows) between the superior and inferior pulmonary veins connect obliquely or directly superior-inferiorly.

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**Pulmonary Venous Component and Left Lateral Ridge**

The posterior part of the left atrium receiving the pulmonary veins is its venous component. Mainly, the wall is smooth on the endocardial surface, without clear distinction between venous and atrial walls, especially where the terminal parts of the veins are funnel-shaped. As mentioned previously, the posterior left atrial wall is not uniform in thickness (Figure 6A). The area between the ipsilateral pulmonary venous orifices has a very scanty content of fibro-fatty tissue. Transmurally, the musculature of the wall shows changes in orientation of the myocardial strands.\textsuperscript{1,26} The subendocardial strands at the veno-atrial junctions are mainly loop-like extensions of the longitudinal and oblique strands from the atrial wall. Abrupt changes in orientation of the strands in the subendocardium may be observed in the interpulmonary areas, where obliquely or circumferentially aligned myocardial strands meet with predominantly longitudinally aligned strands (Figure 6A and 6B). Usually the area of abrupt change is accompanied by a change in wall thickness, thicker toward the septum and thinner laterally.

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**Figure 7.** A, This is a view of the roof and posterior wall of the left atrium with transillumination to demonstrate the thinner parts of the walls. The epicardium has been removed to show the arrangement of the myocardial strands (broken arrows) in the superficial parts of the walls. B, This view of the posterior and inferior walls shows abrupt changes in orientation of the myocardial strands (broken arrows). An interatrial muscle bundle is present in this heart (double-headed arrow). C, This view of the lateral left side shows the myocardial strands in the region between the left superior (LS) and left inferior (LI) pulmonary veins (arrow). D, Muscle bridges (arrows) between the superior and inferior pulmonary veins connect obliquely or directly superior-inferiorly.
is only one pathway of muscular continuity, and this is through the specialized myocytes of the atrioventricular conduction system originally described by Tawara in 1906.41 From the perspective of the left atrium, the atrioventricular node and bundle are related to the vestibular portion that overlies the right fibrous trigonal area of aortic-mitral fibrous continuity. An approximate landmark could be the posteromedial commissure of the mitral valve.

Although the distal border of the vestibule on the endocardial aspect could be taken as the mitral valve, the proximal border is unclear, especially in the anterior, septal, and inferior portions. The quadrant relating to the left atrial appendage, however, usually has series of pits and troughs in the atrial wall, in stark contrast to the smooth vestibular wall. The mitral isthmus extends between the orifice of the left inferior pulmonary vein and the mitral hinge line (Figure 8). Thus, when traced from the venous orifice, the isthmus traverses the atrium’s posteroinferior wall, including the corresponding quadrant of the vestibule.42,43 The length is 35 ± 7 mm when measured in a series of normal heart specimens without history of atrial fibrillation.42 The average of the maximal myocardial thickness of the wall is 3.8 ± 0.9 mm in the midportion; the thickness tapers at either end. From the annulus, the first 5 mm of the vestibular part is thin, with a myocardial depth of 1.5 ± 0.7 mm. Additionally, where the endocardial surface of the isthmus contains pits and troughs, the atrial wall becomes exceptionally thin. Some pits are “foramina Lannelongue,” draining small cardiac veins. Passing along the epicardial side is the great cardiac vein that continues into the coronary sinus. The circumflex artery is also in the vicinity, and in some hearts its wall is in contact with atrial myocardium (Figure 8A).

**Interatrial Muscular Connections**

Apart from muscular continuity at the rim and floor of the oval fossa, there are multiple muscular bridges between the atrial chambers.1 Composed of ordinary atrial myocardium, these bridges are of varying widths, thicknesses, and proximity to the musculature of the true atrial septum.26,31 Muscular bridges between veins and atrial walls are not uncommon.

The prevalent interatrial conduction pathway for propagation of the sinus impulse to the anterior left atrial wall is through the Bachmann bundle, which is also known as the interauricular band (Figure 9A, 9B, and 9C). Indeed, it is the most prominent muscular interatrial bridge in majority of hearts.44,45,46 It is superficially located, composed of nearly parallel alignment of myocardial strands that blend into the musculature of the atrial walls. It branches in its rightward and leftward extensions to embrace the atrial appendages. Myocardial strands from its superior rightward arm can be traced toward the location of the sinus node, the terminal crest, and sagittal bundle. Leftward, the Bachmann bundle runs along the anterior left atrial wall, where it merges with the superficial and circumferentially arranged myocardial strands of the subepicardium, adding to the wall thickness. After passing around the neck of the left atrial appendage, the arms rejoin to continue into the musculature of the lateral and posteroinferior atrial walls.46 The only place where the Bachmann bundle appears as quite a distinct bundle, separated by fatty tissues from atrial wall, is at the anterior interatrial groove (Figure 9B and 9C). A small series studied by Becker revealed more pronounced fibro-fatty replacement of the
myocardium in the terminal crest and in the Bachmann bundle in hearts from patients with atrial fibrillation than without atrial fibrillation. Conceivably, with more extensive acquired changes in the Bachmann bundle, other interatrial bridges could play an increasing role. In some hearts, the Bachmann bundle may coexist with broad muscular bridges across the posteroinferior interatrial groove, joining left atrial musculature to the intercaval area of the right atrium and to the insertion of the inferior caval vein (Figure 9C). These may provide the potential for inferior breakthrough of the sinus impulse instead of the anticipated anterior breakthrough.

Muscle bridges are observed in some hearts connecting the muscular sleeves of the right pulmonary veins to the right atrium, the superior caval vein to the left atrium, and the coronary sinus to the left atrium. In particular, connections between the muscular wall of the coronary sinus and the remnant of the vein of Marshall to the left atrium are common.

The Neighborhood

Parts of the left atrial body, the entrances of the pulmonary veins, the atrial appendage, and the coronary sinus are in close vicinity to important structures that may be affected by interventional maneuvers that are carried out on and within the left atrium. The epicardial aspect of the left atrium, particularly in the region of the veno-atrial junctions, the interatrial groove, the roof, and the tract of the coronary sinus along the inferior wall, is covered by pads of fatty tissues. Preganglionic parasym pathetic and post-ganglionic sympathetic fibers come together into the fat pads, and ganglonated plexuses populate the subepicardium, which has a double-layered inner lining, the serous pericardium, which encloses the pericardial cavity. One layer is fused to the fibrous pericardium and the other layer lines the outer surface of the heart as the epicardium and as the visceral pericardium that ensheathes the veins and great vessels. The aorta and pulmonary trunk are ensheathed together, whereas the veins are enclosed in another sheath. The junctions between the two layers form the pericardial reflections, one of which is the transverse pericardial sinus located behind the great arteries and in front of the atria. Another, the oblique sinus, lies behind the posterior wall of the left atrium and is a large area of continuity between reflections along the pulmonary and caval veins. However, local variations of reflections around individual pulmonary veins can affect access for complete pulmonary venous isolation from the pericardial space.

The spatial relationship of the anterior atrial wall and plane of the atrial septum to the root of the aorta is relevant in transseptal procedures as well as device closure of PFO and septal defects. The roof of the atrium is related to the bifurcation of the pulmonary arter ies and the left bronchus (Figure 1C). In cases with dilated left atrial chamber, the pulmonary bifurcation may be shifted cephalad to become closer to the underside of the aortic arch, which in turn may compress the recurrent laryngeal nerve. Pai et al reported a case of transient vocal cord paralysis thought to have been caused by a stiff electrode catheter pushed against the atrial roof during ablation. The atrial appendage has important relationships with cardiac and extracardiac structures that are relevant to ablating within its lumen or closing its opening. The os is situated above the left atrioventricular groove, which contains the circumflex artery and the great cardiac vein together with their branches. Our study on cadavers found the course of the left phrenic nerve and its accompanying pericardiophrenic vessels in the fibrous pericardium that was overlying the atrial appendage in majority of cases.

The esophagus, though useful as a portal for echocardiographic imaging, is at risk of damage during left atrial ablation procedures. Understanding the course of the esophagus is essential to reduce the risk of atrio-esophageal fistula after catheter ablation on the posterior wall. The esophagus descends slightly to the left between the trachea and the vertebral column and continues its descent behind the fibrous pericardium that overlies the posterior wall of the left atrium, to the right of the aortic arch, and the right side of the descending thoracic aorta (Figure 10A and 10B). In many patients, the descending thoracic aorta also runs in the vicinity of the posterior wall and in some cases may be apposing the fibrous pericardium.

In a study of cadavers, we found the esophagus in virtual contact with the posterior wall over a distance of 30–53 mm (mean, 42 ±7 mm). Its course may be more toward the right or the left pulmonary venous orifices or more centrally. Furthermore, the esophagus curves to lie beneath the postero inferior wall as it descends toward the diaphragm and may be only a couple of millimeters away from the pulmonary venous orifices and practically in contact with the coronary sinus.
close proximity to the posterolateral and lateral aspects of the superior caval vein and anterior to the superior and inferior right pulmonary vein. It is particularly close to the superior pulmonary vein, with a mean minimal distance of 2.1±0.4 mm in a study made on cadavers. The same study found that the distance was <2 mm in a third of the cadavers, suggesting that it could be at risk of damage during right pulmonary vein isolation. The left phrenic nerve takes an anterior (18%), lateral (59%), or posteroinferior (23%) course on the fibrous pericardium overlying the left heart. The lateral course passes over the tip of the left atrial appendage, whereas the posteroinferior course passes over the roof of the appendage os.

Conclusions

The left atrium has a distinctive atrial appendage and an atrial body that comprises component parts that blend into one another. The patterns of general myocardial arrangement in the left atrial wall and the presence of interstitial muscle bundles may provide some anatomic background to atrial and interatrial conduction. Understanding the structure of the component parts and their relationship to one another and to other cardiac structures is relevant to interventional procedures inside and outside of the left atrium.

Disclosures

None.

References


Figure 10. A and B. Specimens viewed from the tilted right superior and posterior perspectives, respectively, to show the courses of the esophagus (eso) and descending aorta relative to the left atrium (LA). C and D, Right and left views, respectively, to show the courses of the phrenic nerves. RB indicates right bronchus; RPA, right pulmonary artery; SCV, superior caval vein; RI, right inferior; RM, right middle; and RS, right superior pulmonary veins.

The gap between the fibrous pericardium and the anterior aspect of the esophagus is filled with fibro-fatty tissues containing lymph nodes as well as esophageal arteries and the periesophageal plexus from branches of the Vagus nerve. The Vagus nerves pass from behind the root of the lungs to form the right and left posterior pulmonary plexuses. Two branches from the left pulmonary plexus then pass caudally to descend on the anterior surface of the esophagus joining with a branch from the right pulmonary plexus to form the anterior esophageal plexus that pass in close proximity to the left and right pulmonary veno-atrial junctions. The esophageal plexes extend through the diaphragm to become the posterior and anterior vagal trunks that innervate the pyloric sphincter and gastric antrum. We found the distance between the endocardial surface of the left atrium and the esophageal wall to be <5 mm in 40% of the 15 cadavers. Thus, not only the esophagus and its arterial supply but also the nerve plexuses and lymph nodes may be put at risk when ablating the posterior atrial wall. Injury to the periesophageal vagal nerves can result in acute pyloric spasm and gastric hypomotility.

Descending bilaterally along the surface of the fibrous pericardium that envelopes the heart, the phrenic nerves and their accompanying pericardiophrenic artery and vein are in the neighborhood of the left atrial appendage and right pulmonary veins (Figure 10C and 10D). The right phrenic nerve courses in...


Key Words: ablation ▪ atrioventricular node ▪ atrium ▪ conduction ▪ fibrillation
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Siew Yen Ho, José Angel Cabrera and Damian Sanchez-Quintana

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This view of the septal aspect of the left atrium shows the valve of the oval fossa transilluminated. There was complete adhesion of the valve to the muscular rim on the right atrial aspect. Nevertheless, a probe (green rod) can be inserted behind the crescentic free margin of the fossa into a pouch-like space up to the level of the black arrow but it was not possible to enter the right atrium.