The Importance of Atrial Structure and Fibers

S.Y. HO1* AND D. SÁNCHEZ-QUINTANA2

1Cardiac Morphology Unit, National Heart and Lung Institute, Imperial College London and Royal Brompton Hospital, London, United Kingdom
2Departamento de Anatomía Humana, Facultad de Medicina, Universidad de Extremadura, Badajoz, Spain

Atrial structures are important in the current era of cardiac interventions using percutaneous transcatheter procedures. Understanding their locations and component parts helps to reduce risks of procedural-related damage. The general arrangement of the myofibers that make up the atrial walls is reviewed to provide a morphologic basis for atrial conduction and potential substrates of arrhythmias. The right atrium, dominated by its appendage, is characterized by having an extensive array of pectinate muscles. These extend almost perpendicularly from the terminal crest. The left atrium has relatively smooth walls and a small tubular-shaped appendage. The myofibers show changes in orientations when traced through the thickness of the walls. Extensions of atrial myocardium onto the pulmonary veins and the superior caval vein are common. Apart from Bachmann’s bundle, there are other muscular bridges of variable numbers and sizes that provide interatrial connections, connections between the left atrium and the coronary sinus, and connections between the muscular sleeves of the right pulmonary veins and the right atrium. The purpose of this review is to summarize the three-dimensional arrangement of gross atrial structures, the myoarchitecture and variations in muscular interatrial connections. These are important features in intra- and interatrial conduction. Clin. Anat. 22:52–63, 2009.

INTRODUCTION

The atrial chambers have come into prominence in the recent decades due to the development of percutaneous interventional procedures both for the treatment, or alleviation, of structural heart defects and for arrhythmias. Previously conceptualized as mere reservoirs of systemic and pulmonary venous blood, they have functional roles in the dynamics of the cardiac chambers and atioventricular valves as well as being the substrate for conduction of the cardiac impulse. Whilst cellular, molecular, and physiological aspects of the tissues that make up the atrial walls are extremely important, the gross structure of the chambers themselves cannot be neglected in the current era of “minimally invasive” protocols whereby diagnosis is commonly made by imaging and electroanatomic mapping before therapeutic transcatheter interventions. This anatomical review highlights the atrial structures that are important to consider when intervening in the atrial chambers. We shall review the structures pertaining to the normal atria with comments on some anatomic variations and congenital malformations that

Key words: arrhythmia; atrial appendage; atrial septum; conduction system; myoarchitecture

© 2008 Wiley-Liss, Inc.
LOCATION OF THE ATRIA

Tomographic imaging of the heart in situ shows the true location of the cardiac chambers and is particularly helpful to cardiac interventionists for understanding the orientation of cardiac structures in the living condition, a concept McAlpine (1975) had termed **attitudinal** in his elegant and detailed anatomical atlas on the heart and coronary arteries. In examining the heart in isolation, as many anatomists and pathologists do, attitudinal orientation is often forgotten. According to Walmsley (1958), descriptions of cardiac anatomy disregard the cardinal principle of using terms in relation to anatomic position. In this review, we will describe and display cardiac structures in attitudinal fashion adopting the terms proposed by Cosio et al. (1999) wherever possible whilst continuing to use some common terms that are not strictly attitudinal (Fig. 1).

Both the right and left atrial chambers lie to the right of the respective ventricular chambers that they open to (Fig. 1). Viewed from the front, the cavity of the right atrium is right and anterior, while that of the left atrium is mainly positioned posterior and slightly leftward relative to the right atrium. The plane of the atrial septum, therefore, does not run in the sagittal plane. Instead, it is orientated obliquely from anteriorly to posteriorly rightward at an angle of −65° to the sagittal plane. The angle is increased when the left atrium is enlarged, an important consideration when carrying out transseptal puncture.

The posterior wall of the left atrium lies just in front of the tracheal bifurcation and in close proximity to the descending course of the esophagus (Sánchez-Quintana et al., 2005a). The pulmonary veins enter the posterior part of the left atrium with the left pulmonary veins located more superiorly than those of the right pulmonary veins. Image integration systems can display in exquisite detail the variations in number of veins, their locations, and angulations of their insertions into the left atrium to guide electrophysiologists who carry out ablations to isolate electrically the pulmonary veins (Kato et al., 2003; Dong et al., 2007). Anteriorly, the walls of both atria form a curve to accommodate the aortic root arising from the middle of the heart (Fig. 1). Considering only the atria, on the right side, the cardiac margin is formed by the parietal wall of the right atrial appendage, often including the course of the terminal crest. On the left side, the left atrial appendage forms the atrial margin. Furthermore, owing to the different levels of the orifices of the mitral and tricuspid valves, not only is the left atrial chamber more posteriorly situated than the right atrial chamber it is also more superiorly situated. Related to the posteroinferior wall of the left atrium is the coronary sinus, which is the continuation of the great cardiac vein. Thus, in attitudinal orientation, the coronary sinus runs from posterosuperiorly to anteroinferiorly when viewed from the anterior aspect of the chest or from superiorly to inferiorly when viewed from a left and anterior perspective. 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. In the majority of individuals, the lumen of the vein is obliterated, and it becomes a fibrous strand. Infrequently, the lumen remains patent and it is described as a persistent left superior caval vein draining into the coronary sinus.

COMPONENTS OF THE ATRIA

The two atrial chambers differ in shape and have characteristic features that allow distinction between morphologically right from morphologically left atria irrespective of their location in the chest. For convenience, we use the heart with normal arrangement of the atria as the standard and describe the chambers as right and left atria in this article. Both atria have the same basic and anatomically identifiable components: a venous portion, an appendage, and a vestibule that leads to the atrioventricular valves (Fig. 1). The chambers are separated by the atrial septum. Following the direction of blood flow, each atrial chamber begins at the venoatrial junctions that are the entrances of the caval veins or the pulmonary veins and terminates at the fibro-fatty tissue plane that marks the atrioventricular junction. The atrial walls are composed of atrial myocardium of varying thicknesses. In many hearts, atrial myocardium can be found beyond the atrial boundaries as muscular sleeves around the outer aspects of the ve-
norous walls and extending for varying lengths toward the lung hilum (Ho and Sánchez-Quintana, 2000; Saito et al., 2000) These sleeves are well illustrated in the landmark work of Keith and Flack (1907) documenting their discovery of the sinus node (Fig. 2). Muscular sleeves have come under scrutiny amongst cardiac electrophysiologists in the recent decade owing to their association with focal activity initiating atrial arrhythmias (Haissaguerre et al., 1998; Kholová and Kautzner, 2004) (vide infra). At the outlets of the atri and the myocardium of the distal parts of the vestibule overlap the atrial surface of the leaflets of the tricuspid and mitral valves to a greater or lesser degree albeit only for distances of a millimeter or so. The atrial myocardium, however, is electrically isolated from ventricular myocardium owing to the insulation provided by fibro-fatty tissues at the hinges of the valves. It is well recognized that for normal conduction of the cardiac impulse from atria to ventricles there 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.

STRUCTURE OF THE RIGHT ATRIUM

The dominant feature of the right atrium is its large appendage, an outpouching from the body of the atrium. The triangular shaped appendage projects anteriorly and its apex points superiorly (Fig. 1B). The parietal wall of the appendage, continuous with the wall of the venous component, occupies the lateral margin of the right atrium (Fig. 1A). Characteristic of the right atrium is the terminal crest visible on the endocardial surface. It is the muscle bundle that delineates the border between the smooth wall of the venous component and the rough wall of the appendage (Fig. 3). The crest extends from the anteromedial wall on the left side of the entrance of the superior caval vein, passes rightward in front of the venous orifice before descending laterally, curving to the right of the entrance of the inferior caval vein to continue as an array of finer bundles that enter the region of the atrial wall recognized as the inferior isthmus or cavitricuspid isthmus. This is the critical part of the circuit in common atrial flutter that is ablated so as to create a line of conduction block in patients with common atrial flutter (Fig. 4). The nonuniform arrangement of the terminal ramifications of the crest may account for delay and discontinuities in the spread of the excitatory wavefront and lead to atrial re-entry (Waki et al., 2000; Sánchez-Quintana et al., 2002; Cabrera et al., 2005). The medial origin of the crest corresponds on the epicardial side to the right atrial insertion of Bachmann's bundle that will be discussed in a later section concerning interatrial bundles. Myocytes within the terminal crest are aligned mainly longitudinally along the long axis of the muscle bundle (Sánchez-Quintana et al., 2002) favoring preferential conduction. By contrast, those in the intercaval area adjoining, the terminal crest is arranged obliquely producing a sudden change in myofiber orientations or intermingling of irregularly arranged myofibers.

From the lateral margin of the crest arises a series of muscle bundles known as pectinate muscles that fan out from the crest toward the vestibular portion (Fig. 3). One of the anterosuperior bundles is usually more prominent, and it is described as the “septum spurium” or “sagittal muscle bundle,” a convenient landmark for dividing the appendage into anterome-

Fig. 1. These pictures of an endocast from a normal heart viewed from (A) the front, (B) the right, and (C) the left show the arrangement of the cardiac chambers relative to one another in attitudinal orientation. The smooth endocardial surfaces of the venous and vestibular components of the atrial chambers are in stark contrast to the ridged and surfaces of the atrial appendages. Note the course of the coronary sinus relative to the left atrium in (C). Ao, aorta; ICV, inferior caval vein; LAA, left atrial appendage; LI, left inferior pulmonary vein; LV, left ventricle; LS, left superior pulmonary vein; PT, pulmonary trunk; RAA, right atrial appendage; RI, right inferior; RS, right superior pulmonary vein; RV, right ventricle; SCV, superior caval vein.

Fig. 2. A: This diagram from Keith and Flack (1907) shows the myocardial sleeves around the pulmonary veins and the caval veins. The line between the asterisks represents the plane of section through the sinus node. B: This heart specimen is viewed from the back, approximately in the same orientation as the heart depicted in the diagram. The epicardium has been removed from the left atrium to reveal the myoarchitecture and the venous sleeves. The broken line marks the site of the sinus node. In the heart, there is a broad muscle band (arrow) connecting the left atrium to the intercaval area of the right atrium. LI, LS, RI, RS, left and right inferior and superior pulmonary veins, respectively; ICV and SCV, inferior and superior caval veins, respectively.

Fig. 3. (A) and (B) show the same heart specimen with the parietal wall of the right atrial appendage deflected posteriorly. (B) is photographed with transillumination to display the thin wall between the pectinate muscles. The terminal crest (broken line in all panels) passes in front of the mouth of the superior caval vein (*) before descending laterally. The short arrows indicate the sagittal muscle bundle. The venous component (double headed arrow) between the caval veins is smooth walled as is the vestibule. (C) shows nearly parallel arrangement of the pectinate muscles and (D) shows a variation with fan-like arrangement and many cross-cross branches. (E) is a scanning electron micrograph of a terminal crest showing predominantly longitudinal alignment of myocytes. CS, coronary sinus; OF, oval fossa.
dial and posterolateral components. The pectinate muscles line the wall of the appendage as a series of interconnecting ridges interspaced with very thin areas that are almost lacking in musculature. In some hearts, the ridges along the parietal wall are aligned in nearly parallel fashion. In others, the ridges are not as uniformly arranged but have abundant cross-overs with thin-interlacing strands in between (Sánchez-Quintana et al., 2002) (Fig. 3A). Myofibers in the ridges tend to run longitudinally along their lengths. All the ridges terminate in the vestibule, leaving a smooth portion of atrial wall around the atrial outlet that is composed mainly of a circumferential arrangement of subendocardial myofibers perpendicular to the myofibers in the ridges.

Smooth walls also characterize the venous component of the right atrium. The terminal crest marks the division between the ridge-lined atrial appendage and the smooth venous part. The posterior atrial wall between the orifices of the superior and inferior caval veins is also known as the intercaval area (Fig. 3). The entrance of the superior caval vein is not guarded by a valve. It is common to find sleevelike extensions of right atrial myocardium on the outer aspects of the venous wall to varying extents (Kholová and Kautzner, 2004). The distal margins of the sleeves are often irregular. The sinus node lies in the musculature of the terminal crest, usually at the anterolateral junction with the superior caval vein (Truex et al., 1967; Sánchez-Quintana et al., 2005b) (Fig. 2). Short extensions from the nodal body into atrial myocardium are common. Occasionally, these strands can be traced into the venous sleeves.

By comparison, the extent of myocardial coverage over the inferior caval vein is considerably less or absent in cases. The lack of myocardium may also involve the inferior part of the intercaval wall. Furthermore, the entrance of the inferior caval vein is guarded by a valve known as the Eustachian valve. Usually, the valve is a triangular flap of fibrous or fibromuscular tissue extending from the lateral margin of the caval orifice to anteriorly and leftward to join the sinus septum that is the border between the mouth of the coronary sinus and the oval fossa. Occasionally, the Eustachian valve is in the form of a large fenestrated Chiari network that may entangle catheters entering the right atrium from the inferior caval vein. The sinus septum, also known as the Eustachian ridge, is not truly septal. It is the atrial wall between the inferior caval vein and the coronary sinus. The orifice of the coronary sinus is usually smaller than the caval veins, but it may become considerably enlarged when it receives more than its normal venous return, for example, in patients with persistence of the left superior caval vein. Often the Thebesian valve guarding the coronary sinus at its entrance to the right atrium is a small crescentic flap, sometimes with fenestrations (Fig. 4A). Occasionally, the valve is more extensive and may be a cause of obstruction when trying to insert a catheter into the sinus.

The vestibule of the tricuspid valve marks the outlet from the right atrium and the termination of atrial myocardium. Because the orifice of the tricuspid valve is orientated in a plane approximating to the long axis of the body rather than horizontally, the vestibular component is similarly orientated. Thus, the triangle of Koch, which is the anatomical landmark for the location of the atrioventricular node, is the portion of the vestibule that passes anterior to the orifice of the coronary sinus and turns upwards and medially. The vestibular wall at the base of the triangle between the coronary sinus and the annular attachment of the septal leaflet of the tricuspid valve forms the “septal” isthmus while the line of leaflet attachment forms the anterior border of Koch’s triangle (Fig. 4). At the triangle’s posterior border is the tendon of Todaro that passes within the sinus septum and inserts into the membranous septum that is at the apex of the triangle (Ho and Anderson, 2000). It is at this point that the atrioventricular conduction system penetrates the insulating plane of the atrioventricular junctions to form the bundle of His, which is the atrioventricular nodal equivalent. The constitutions of the atrioventricular conduction bundles. The constitution of the atrioventricular node, in particular, its inferior extensions as described by Inoue and Becker (1998) have been implicated in atrioventricular nodal re-entrant tachycardia in the report by Katritsis and Becker (2007). Because the rightward prong of nodal extension passes inferiorly, the so-called septal isthmus is targeted by ablationists (Fig. 4). Anatomically, however, the “septal” isthmus is not truly septal but is the inferior part of the anteromedial wall of the right atrium that, when punctured, leads to the inferior pyramidal space, an area well recognized by cardiac surgeons in the days of surgical avulsion of accessory atrioventricular pathways (Sealy and Gallagher, 1980; Sánchez-Quintana et al., 2001). Another clinically important isthmus formed in part by the vestibule is the cavotricuspid isthmus or inferior isthmus that has been described in a previous section.

**STRUCTURE OF THE ATRIAL SEPTUM**

Partitioning the atrial chambers, the true atrial septum is limited to the floor of the oval fossa and its immediate muscular rim at the anteroinferior part, which is confluent with the apical part of Koch’s triangle (Fig. 5). The major part of the muscular rim (also known as the limbus) is an infolding of the right atrial wall representing the embryonic “septum secundum,” and the rim is a characteristic feature of the septal aspect of the right atrial. The fold is evident when the septum is transected. Epicardial fat fills the groove, which is also known as the septal raphe (Fig. 5) (Papez, 1920). The floor of the fossa is the valve that closes shut against the rim so long as the blood pressure in the left atrium exceeds that in the right atrium. For this to happen, the valve has to be large enough to overlap the rim. Closure of the fossa is complete when the valve becomes adherent to the rim. In ~25–30% of the population, the seal is incomplete leaving a crevice at the anterosuperior quadrant of the rim that allows a probe to be passed obliquely from the right atrium. The probe patent fossa (patent foramen ovale) is thought to be a source or route for paradoxical emboli that could cause
Fig. 4. A: The orifice of the coronary sinus (arrow) is guarded by a fenestrated Thebesian valve. The broken lines mark the anterior and posterior margins of the triangle of Koch. At the apex, lies the membranous septum that appears a paler color. The irregular shape marks the anticipated site of the compact atrioventricular node with its inferior extensions. The short dotted line marks the “septal” isthmus, and the long dotted line marks the cavo-tricuspid isthmus. B: This specimen is displayed in similar orientation and has been dissected to show the subendocordial myoarchitecture. The landmarks for the triangle of Koch and isthmuses are superimposed. Note the nonuniform arrangement of the muscle bundles with intervening fibrous walls in the posterior component of the cavo-tricuspid isthmus.

Fig. 5. This longitudinal section through the heart profiles the atrial septum to display the valve of the oval foramen (arrow) and the muscular rim on either side. The infolding of the right atrial wall encloses epicardial fat (asterisk). The dotted lines mark the annular attachments of the tricuspid (TV) and mitral (MV) valves. The solid arrow indicates the so-called left atrial ridge that is a fold in the atrial wall in between the left atrial appendage (LAA) and the left superior pulmonary vein (LS). CS, coronary sinus; ICV, inferior caval vein; LI, LS, RI, RS, left and right inferior and superior pulmonary veins, respectively.
migraines. On the left atrial side, the crevice is marked by the crescentic free-edge of the valve (Fig. 6). The floor of the oval fossa varies considerably in dimensions as does the thickness of the muscular rim (Schwinger et al., 1990). Prominent muscular rims are helpful to interventionists to feel a “jump” as the tip of the catheter drops into the flap valve allowing the valve to “tent” into the left atrium when carrying out transseptal punctures. Crossing the “septum” too anteriorly runs the risk of exiting the right atrium into the transverse pericardial sinus and beyond into the aortic root. The flap valve guarding the oval fossa is usually thin, with a bilaminar crossing arrangement of myofibers and varying amounts of fibrous tissue. In some hearts, it is thinner and aneurysmal in appearance as it herniates into the atrial chambers through the respiratory cycle.

Myofibers in the rim of the fossa are arranged predominantly in circular fashion around the fossa. Crossing the atrium can be accessed from the right atrium through a crevice (between arrows) that is the last part of the valve to be sealed to the rim. In this heart, the course of the coronary sinus (cs) is distant from the mitral valve. Ao, ascending aorta.

**Fig. 6.** This heart sectioned longitudinally in a plane parallel to that of the atrial septum shows the relatively smooth walls of the left atrium. The rim of the oval fossa on the right atrial side is marked by the circle. When there is probe patency of the oval fossa, the left atrium can be accessed from the right atrium through a crevice (between arrows) that is the last part of the valve to be sealed to the rim. In this heart, the course of the coronary sinus (cs) is distant from the mitral valve. Ao, ascending aorta.

**Fig. 6.**

Fig. 7. **A:** This dissection reveals the subepicardial myoarchitecture of the atria viewed from the front. Myofibers of Bachmann’s bundle (BB) and the septopulmonary bundle (SP) run in different orientations. The septopulmonary bundle arises from the anterosuperior septal raphe behind Bachmann’s bundle. **B:** The posteroinferior aspect of the atrial chambers shows multiple muscular bridges (small arrows) across the posterior and inferior parts of the septal raphe. ICV, inferior caval vein; SCV, superior caval vein; LAA and RAA, left and right atrial appendages respectively; LI, LS, RI, RS, left and right inferior and superior pulmonary veins respectively.

**Fig. 7.**

**Fig. 8.** This diagram adapted from Ho et al. (1999) shows the pattern of myoarchitecture generally found in the left atrial wall. The upper panels represent the anterior aspect of the atrial chambers shows multiple muscular bridges (small arrows) across the posterior and inferior parts of the septal raphe. ICV, inferior caval vein; SCV, superior caval vein; LAA and RAA, left and right atrial appendages respectively; LI, LS, RI, RS, left and right inferior and superior pulmonary veins respectively. The lower panels represent the posterior aspect, tracing the myofibers from the subepicardium to the subendocardium.
Toward the periphery, the myofibers radiate toward the terminal crest superiorly and the intercaval region posteriorly. From the anterior rim, myofibers pass forward toward the apex of Koch's triangle.

STRUCTURE OF THE LEFT ATRIUM

Unlike the right atrium, the left atrial chamber is not dominated by its appendage. The atrial appendage of the left atrium is considerably smaller and tends to have a tubular shape that has one or several bends resembling a little finger (Stöllberger et al., 2003) (Fig. 1C). The morphology of the left appendage varies considerably but owing to its tubular shape it has a distinct junction with the body of the left atrium. The rough zone of the left atrium is confined mainly to its appendage. A complicated network of fine muscular ridges lines the endocardial aspect. In between the ridges, the wall is parchment thin. The left atrium lacks a terminal crest. The body of the left atrium, as distinct from the appendage, joins together the vestibule, septum, and venous component and has relatively smooth walls. Nevertheless, pits and troughs sometimes arranged in series to give the atrial wall the appearance of muscular ridges are often seen in the vicinity of the os to the appendage and in the inferolateral wall between the orifice of the left inferior pulmonary vein and the mitral vestibule (Su et al., 2007).

The posterior part of the left atrium receiving the pulmonary veins is its venous component. It lies immediately in front of the esophagus, separated only by the fibrous pericardium (Sanchez-Quintana et al., 2005a). There is a potential risk of damaging the esophagus when ablating in the posterior wall since the wall thickness is not uniform (Platonov et al., 2008). The wall is smooth but the endocardial surface has the appearance of ridges in between the superior and inferior venous orifices. In particular, there is a ridgelike structure between the entrance of the left superior pulmonary vein and the orifice of the left atrial appendage (Fig. 5). This is no more than an infolding of the atrial wall. Within the fold runs the remnant of the vein of Marshall and accompanying neural elements.

Traditionally, the venous component is illustrated as having four pulmonary veins entering separately, two from the left lung and two from the right lung. Improvements in imaging techniques are now able to show considerably more variations in number of venous orifices and their arrangements (Kato et al., 2003; Wazni et al., 2006). Indeed, our study on a series of 35 heart specimens found the classical arrangement of four orifices in 69, and 31% with a variable length of 3–15 mm of conjoined vein on one or both sides. The remaining 9% had a common vein that reached the lung hilum on the left or the right sides (Ho et al., 2004). The right superior pulmonary vein passes next to the posterior aspect of the right atrium immediately behind the junction with the superior caval vein. It is at this location that its anterior wall is closest to the course of the right phrenic nerve (Sanchez-Quintana et al., 2005c). The orifices of the right pulmonary veins are directly adjacent to the plane of the atrial septum.

The transition between atrium and vein is smooth. On gross examination, it is difficult to distinguish a venoatrial junction especially if the vein enters the atrium like a funnel. Like the caval veins, atrial musculature extends over the walls of the pulmonary veins to varying extents circumferentially and distally (Nathan and Eliakim 1966; Ho and Sanchez-Quintana, 2000; Saito et al., 2000; Ho et al., 2001) (Fig. 2). The sleeves of ordinary atrial myocardium are more extensive in the superior veins than in the inferior veins. Electrical activity in venous sleeves have long been recognized (Zipes and Knope, 1972), but it is only within the past decade that ectopic foci of activity from the veins have been linked to spontaneous initiation of atrial fibrillation (Haissaguerre et al., 1998), resulting in focal ablations or electrical isolation of the pulmonary veins being included in therapeutic strategies for this arrhythmia.

As in the right atrium, the vestibular portion marks the left atrial outlet. Without an extensive atrial appendage, however, the proximal margin of the mitral vestibule blends in with the smooth wall of the atrial body. The margin is clearer in some hearts that have a series of pits and grooves in the inferolateral wall. The vestibule forms part of the so-called mitral isthmus between the orifice of the left inferior pulmonary vein and the annular attachment of the mitral valve (Wittkampf et al., 2005). The coronary sinus runs along the epicardial side of the inferior quadrant of the vestibule at variable distances from the annular attachment of the mitral valve (Fig. 6).

Although the body of the left atrium has relatively smooth walls, it is by no means uniform in thickness or in myoarchitecture. Detailed dissections of the atrial wall transmurally have shown a complex architecture of overlapping myofibers of different orientations giving the impression of layers but these are not separated by sheaths of insulating fibrous tissue (Papez, 1920; Wang et al., 1995; Ho et al., 1999, 2002). There are individual variations from heart to heart but, in general, the myoarchitecture conform to the pattern first shown so elegantly in human hearts by Papez in 1920. From the epicardial aspect, it is common to find a broad muscle bundle that runs along the anterior atrial wall. Known as Bachmann’s bundle, it is composed of myofibers that are aligned in parallel fashion to the plane of the atrioventricular junction (Fig. 7A). Deeper than Bachmann’s bundle and inferior to it are myofibers arising from the anterior rim of the oval fossa. These blend into Bachmann’s bundle to pass leftward to the lateral wall. They pass to either side of the neck of the atrial appendage and then reunite as a broad band circumferentially around the inferior wall to enter the septal raphe. Arising from the anterosuperior septal raphe is a broad array of longitudinally to obliquely arranged myofibers that pass beneath Bachmann’s bundle to surface onto the atrial roof. The myofibers of this bundle, termed the “septopulmonary bundle” by Papez (1920), fan out to pass in front, between, and behind the insertions of the pulmonary veins,
joining with the muscular sleeves of the veins (Fig. 7). On the posterior wall, the septopulmonary bundle often becomes two diverging branches that fuse with and become indistinguishable from the circumferential myofibers coming from the lateral wall.

Deeper than the septopulmonary bundle and forming the subendocardium is the “septoatrial bundle” (Papez, 1920) (Fig. 8). This bundle arises from the anterior septal raphe as an array of obliquely arranged myofibers, combines with the oblique myofibers from the anterior vestibule and myofibers from the septopulmonary bundle to the atrial roof and continues in between the orifices of the left and right pulmonary veins on the posterior wall. It is common to find extensions from the septoatrial bundle forming loops around the area of the venoatrial junctions. Often, these can be traced to the circular myofibers of the venous sleeves. In some cases, however, the subendocardial myofibers are longitudinal, along the long axis of the vein, while the subepicardial myofibers encircle the veins. Although circularly arranged myofibers dominate in the venous sleeves, oblique and longitudinally arranged myofibers often interdigitate with circular myofibers producing nonuniform anisotropic arrangements that may be the substrate for micro-re-entry while sudden changes in orientations may promote exit of activation from a focal source (Hocini et al., 2002; deBakker et al., 2002). Branches from the septoatrial bundle also pass leftward into the lateral wall. Some of the myofibers encircle the mouth of the atrial appendage and others continue into the fine ridges lining the cavity of the appendage.

**INTERATRIAL MUSCULAR CONNECTIONS**

Apart from muscular continuity at the margins and the floor of the oval fossa, there are muscle bundles that allow conduction between the atria (Fig. 9). These interatrial muscular connections are composed of ordinary atrial myofibers. The bundles are of varying widths and sizes and proximity to the rim of the oval fossa (Ho et al., 1999). Some run adjacent to the rim while others are peripheral to the immediate rim (Mitrofanova et al., 2005). Acquired changes in these bridges may result in conduction loss or prolongation that potentiates re-entrant activation (Sakamoto et al., 2005). In majority of hearts, the most obvious muscular interatrial bridge is Bachmann’s bundle. Its rightward and leftward insertions fan out to blend into musculature of the atrial walls. Nevertheless, its rightward insertion is mainly on the epicardial side of the terminal crest anterior to the mouth of the superior caval vein and close to the site of the sinus node. Here, the myofibers of Bachmann’s bundle are usually perpendicular to those of the terminal crest. Occasionally, Bachmann’s bundle is small or absent. In these cases, broad muscular bridges may be seen across the inferior or the posterior septal raphe. This arrangement may account for inferior breakthrough of the sinus impulse instead of the anticipated anterior breakthrough (De Ponti et al., 2002). The rightward extension of the septopulmonary bundle often continues across the septal raphe into the intercaval musculature as fine bundles and occasionally as a substantial band.

Muscular bridges between veins and atrial walls also have the potential of allowing interatrial conduction. Connections between the muscular wall of the coronary sinus to the left atrium are common (Lüdinghausen et al., 1992; Chauvin et al., 2000). During our dissections, we have also seen fine muscular strands connecting the muscular sleeves of the right pulmonary veins to the right atrial wall and some connecting the muscular sleeve of the superior caval vein to the left atrium.
CONCLUSIONS

The atrial chambers have distinctive topographic features in the right and left atria. The right atrial wall is dominated by an extensive inner surface lined by ridges, whereas the left atrial surface is smoother. In both atria, the structure of the walls and the atrial septum confers a three-dimensional arrangement of muscle bundles and myoarchitecture that allows preferential conduction of electrical activity without the need for tracts of specialized myocytes to link the sinus and atrioventricular nodes (Janse and Anderson, 1974; Anderson et al., 1981). Marked changes in orientation, for example, in subendocardial myofibers may account for functional lines of block observed during endocardial activation as reported by Markides et al. (2003). The heterogeneous transmural and transseptal myoarchitecture should be taken into account when developing computer models to study atrial arrhythmias. With refinements in electroanatomic mapping, the three-dimensional contribution to human atrial activation has been shown recently in the study by Lemery et al. (2007). Knowledge of atrial structure even at the macroscopic level is important for a better understanding of atrial activation and arrhythmias, and it reduces risks associated with interventional procedures.

REFERENCES


