Atrial Anatomy

With the increasing focus on Atrial Arrhythmias and on Atrial Fibrillation in particular, a thorough understanding of the anatomy of the atrial structures is mandatory for those working in or associated with cardiology.

Improved knowledge about the anatomy and the electrophysiologic properties of the atria, is leading to new treatment modalities such as new drugs, linear- and focal ablation, compartmentalization by surgery or RF ablation and implantable devices.

Professor R.H. Anderson is demonstrating in his unique way the detailed anatomy of the atria and its conduction system utilizing prepared human hearts. He shows the heart in its true anatomic position, which makes it easier to interpret X-Rays from the EP lab. He clearly points out possible re-entrant circuits and where catheters are placed to measure and to ablate.

A book and the accompanying video on this subject is a must for anyone who is interested in the field of electrophysiology or who wants to improve his/her knowledge about atrial arrhythmias.
INTRODUCTION

The atrial chambers have tended to be the Cinderellas in terms of cardiac structure. Within the last few years, however, the upsurge in the treatment of abnormal cardiac rhythms by ablation, surgery and implantable devices, has highlighted the need to permit the interventionist to guide catheters to produce the linear ablations now proving to be curative for so many atrial rhythms. Similarly, the interest in antitachycardia pacing by bi-atrial pacing, dual-site atrial pacing and the utilization of novel pacing algorithms, has provoked a search for other electrode positions as opposed to standard pacing techniques.

In this booklet, and in the videotape which it accompanies, therefore, I will describe and demonstrate atrial anatomy in attitudinally correct fashion.
OVERALL CARDIAC STRUCTURE

So as to account fully for any three-dimensional structure, it is always necessary to account for its three orthogonal planes. In this context, the heart has its own sets of orthogonal planes, two in the long and one in the short axes (Figure 1).

It does not help the clinician, however, to use the intrinsic cardiac axes as the basis for description. This is because, during life, the heart is self-evidently contained within the body. The “gold standard” for description of the various parts of the body is the so-called “anatomical position” (Figure 2). When describing the interrelationships of the cardiac components, therefore, and for the purposes of these discussions I concentrate on the atrial chambers, it is necessary to account for them within the framework of the body. Thus, with the heart positioned as it lies within the body, all parts towards the head are up, and are said to be superior. Those towards the feet are down, or inferior. Those components located towards the spine are then posterior, while those towards the sternum are anterior. The final two descriptors are right and left, as indicated by the location of the hands. Proper use of these adjectives is the basis for attitudinally correct description.

BASIC DESCRIPTION OF THE HEART

When seen in frontal projection, the cardiac silhouette is trapezoidal, with its longer inferior margin resting on the diaphragm (Figure 3).

The right border of the heart has a convex configuration, while the left border slopes markedly downwards and inferiorly. Within this silhouette, it is the right atrium which forms the right border, with the superior and inferior caval veins entering at its upper and lower margins. Very little is seen of the left atrium, with only the tip of the left atrial
appendage being visible as it peeks round the lateral border of the pulmonary trunk (Figure 4).

It is necessary to view the heart from its diaphragmatic aspect to reveal the location of the left atrium, which is the most posterior of the four cardiac chambers. Each of the pulmonary veins enters the atrium at its corners, the connections to the lungs serving to anchor the heart within its mediastinal cradle (Figure 5).

**CHAMBERS WITHIN THE HEART**

It follows from the description given above for the cardiac silhouette that the so-called right atrium is, in fact, largely in front of, or anterior to, its left-sided counterpart. This is well demonstrated by viewing an endocast of the cardiac chambers in attitudinally correct position (Figure 4). As already emphasized, all that is visible of the left atrium when the heart is viewed from the front is the tip of the left atrial appendage. Viewing the endocast from behind then confirms the essentially posterior location of the left atrium, with the pulmonary veins entering its leftward and rightward borders (Figure 5). The atrial septum, therefore, is more-or-less in the frontal plane, although it has a degree of postero-anterior obliquity when traced from its right to its left borders (Figure 6).

**MORPHOLOGY OF THE RIGHT ATRIUM**

Each atrial chamber possesses a venous component, the vestibule of an atrioventricular junction, and an appendage. The septum then separate the atrial cavities one from the other. In the morphologically right atrium, the appendage is an extensive triangular structure with a characteristic array of pectinate muscles on its luminal aspect. The appendage forms the entire anterior wall of the right atrium (Figure 7), folding round laterally so that its pectinate
muscles extend posteriorly to reach the crux of the heart (Figure 8). Thus, the pectinated wall of the atrium, throughout its extent, interposes between the smooth-walled systemic venous component found posteriorly, and the anteriorly located vestibule of the tricuspid valve, also with smooth walls, (Figures 7, 8). The pectinate muscles themselves are parallel structures which arise at right angles from the most prominent muscular bundle found within the atrium, namely the terminal crest (crista terminalis). When seen in the endocast, the site of the crest is seen as a deep notch between the systemic venous component and the appendage, while the pectinate muscles form parallel horizontal ridges as they extend towards the vestibule (Figures 7, 8).

MORPHOLOGY OF THE LEFT ATRIUM

Although possessing the same components as the right atrium, the proportions and relations of these parts are markedly different in the left atrium. Thus, the appendage is a much smaller tube-like structure which arises from the superior and leftward corner of the chamber (Figure 9). The pectinate muscles are very numerous within the appendage, giving it a coral-like configuration (Figure 10). The pectinate muscles, nonetheless, are confined within the appendage, so there is a markedly greater part of the left atrium with smooth walls. The four pulmonary veins open into the posterior quadrants of this smooth-walled area, which is confluent both posteriorly and anteriorly with the smooth-walled vestibule, (Figure 5).

Encircling the posterior and leftward quadrants of the left atrial vestibule, and running within the atrioventricular groove, is the coronary sinus, with its tributary, the great cardiac vein (Figure 11). Superiorly, the pulmonary venous component extends over the dome of the atrium to reach the anterior margin of the vestibule.
INTERNAL STRUCTURE OF RIGHT ATRIUM

When viewed from the inside, the most obvious feature of the right atrium is its arrangement as a muscular bag full of holes. The walls separating the holes then show further differences as regards their smooth or pectinated luminal surface. Opening the atrium by a window in the pectinated appendage reveals the site of the prominent terminal crest, or crista terminalis, which forms the boundary between the smooth and rough components (Figure 12). Arising from the terminal crest in most hearts, and guarding the orifices of the inferior caval vein and coronary sinus, respectively, are two fibrous sheets of varying dimension known as the Eustachian and Thebesian valves. When traced superiorly, the terminal crest arches over the orifice of the superior caval vein and extends to the area of the anterior interatrial groove. When traced further by dissection, it can be shown that the insertion of the crest at the interatrial groove is the origin of the important muscular fascicle extending into the left atrium known as Bachmann’s bundle (see Figure 28). When traced inferiorly, the terminal crest turns in beneath the orifice of the inferior caval vein, breaking up into a series of trabeculations in the area of the atrial wall known as the inferior isthmus (Figure 13). Anterior to the break-up of the trabeculations, this isthmic area usually contains a deep pouch.
immediately inferior to the mouth of the coronary sinus. In the past, this has been called the sub-Eustachian sinus. But, with the heart orientated as it lies within the body, the pouch is sub-Thebesian (Figure 14). When traced still further anteriorly, the isthmus merges with the vestibule of the tricuspid valve, which itself extends superiorly into the region known as the triangle of Koch (Figure 15). The inferior isthmus, therefore, has three components. The most posterior part is trabecular. The middle part is the pouch-like diverticulum inferior to the coronary sinus, which is largely membranous. The anterior part is the vestibular component, which becomes the septal isthmus as it turns superiorly to enter the triangle of Koch.

The posterior boundary of the triangle itself is the fibrous continuation of the Eustachian valve known as the tendon of Todaro. This can readily be demonstrated in most hearts by superficial dissection (Figure 15). Tension on the valve itself brings the tendon into prominence, accentuating the muscular elevation between the oval fossa and the coronary sinus which is known as the Eustachian ridge (Figure 16). The anterior boundary of the triangle is the line of attachment of the septal leaflet of the tricuspid valve. These two boundaries meet superiorly at the area of the membranous septum (Figure 15). The coronary sinus occupies the base of Koch’s triangle, with the septal isthmus interposed between the anterior margin of the mouth of the sinus and the hinge of the septal leaflet of the tricuspid valve. This is the site for ablation of the slow pathway into the atrioventricular node, the node itself occupying the apex of the overall triangle.
INTERNAL STRUCTURE OF THE LEFT ATRIUM

The internal profile of the left atrium is much simpler than that of the right, since the walls are almost exclusively smooth. The pectinate muscles are confined within the tubular appendage, which buds forwards from the anterior, superior and leftward corner of the chamber (Figure 10). The four pulmonary veins anchor the posterior wall, which is also the most posterior margin of the heart itself, with one vein usually draining to each of the four corners. There then is an extensive smooth superior dome to the chamber which passes anteriorly to extend to the smooth vestibule of the mitral valve. The septum, inclining from left to right when traced anteriorly to posteriorly, has a characteristic roughened appearance on its left atrial surface, with the attachments of the flap valve forming a pair of horns as they are bound down to the infolded superior rim of the oval fossa (Figure 17). In about one-third of the population, there is no anatomic union between flap valve and rim, giving the arrangement known as a probe-patent oval foramen.

Figure 16: The relationship of the Eustachian ridge to the oval fossa and the triangle of Koch.

Figure 17: The posterior wall of the left atrium has been removed to show the arrangement of the left atrial aspect of the septum.

Figure 18: When viewed from the right side, it appears at first as though the atrial septum is an extensive structure.
STRUCTURE OF THE ATRIAL SEPTUM

At first sight, when looking through the parietal wall of the right atrium (Figure 18), there is an extensive muscular area around the prominent oval fossa which potentially separates the cavity of the right from the left atrium. The extent of the true septum, however, is much more limited. This is because there is a deep fold superiorly and posteriorly between the attachments of the caval veins to the right atrium and the right pulmonary veins to the left atrium (Figure 19). Sectioning across the fossa shows that this extensive interatrial groove, is filled with extracardiac fat (Figure 20). Thus, although forming an extensive buttress at the rim of the oval fossa, the fold is not a true septal structure. Only the fibromuscular flap valve, and the infero-anterior muscular rim, are walls interposed between the right and left atrial cavities. The anterior margin of the oval fossa is directly related to the non-coronary sinus of the aortic valve (Figure 21), this relationship being of note for those seeking safely to achieve septal puncture.

Figure 19
Dissecting the posterior wall shows the extensive groove between the connections of the caval veins to the right atrium and the pulmonary veins to the left atrium. This is Waterston’s, or Sondergaard’s, groove.

Figure 20
Sectioning the heart in “four-chamber” fashion shows how the so-called “septum secundum” is, in reality, the deep superior interatrial groove.

Figure 21
Removing the non-coronary sinus reveals the relationship of the triangle of Koch, and the anterior interatrial groove, to the left-sided chambers.
LOCATION OF THE CONDUCTION TISSUES

Within the right atrium are found several important components of the specialized system of cardiac muscle which initiates and conducts the heartbeat. The impulse is generated by the sinus node. This small, cigar-shaped, structure is located immediately sub-epicardially within the terminal groove, the groove itself being the external landmark of the terminal crest which marks the junction between the appendage and the systemic venous component of the right atrium (Figure 22). In nine-tenths of the population, the node is located laterally, being positioned just inferior to the prominent crest of the appendage, with a length of one to two centimeters. In the remaining one-tenth, the node straddles the crest in horseshoe fashion, with one limb extending down the terminal groove, and the other running into the interatrial groove.

The impulse from the node is disseminated through the atrial chambers by the ordinary myocardium making up their walls. There are no insulated tracts coursing through these walls. There is, nonetheless, preferential conduction. This is determined, first, by the geometric arrangement of the
chambers themselves, which are no more than muscular bags full of holes. Further potential for preferential conduction is provided by the anisotropic arrangement of the muscular fibers. Parallel array of the fibers promotes faster conduction in the major bundles of the right atrium such as the terminal crest and margins of the oval fossa (Figure 23). Preferential conduction to the left atrium is then potentiated by the extension of the terminal crest through the interatrial groove. This latter pathway, which extends to the roof of the left atrium, is known as Bachmann’s bundle (Figure 24).

The remaining components of the atrial specialized tissue are then located in the atrial myocardium forming the surface of Koch’s triangle (Figure 25). The triangle is demarcated by the tendon of Todaro and the attachment of the septal leaflet of the tricuspid valve, with its base at the mouth of the coronary sinus. The atrioventricular node is found towards the apex of the triangle, with the specialized muscular axis providing conduction continuing beyond the node as the penetrating atrioventricular bundle, or the bundle of His (Figure 26). It is difficult, if not impossible, to distinguish histologically between the most distal part of the node and the proximal portion of the bundle. Instead, the distinction between the two is best taken as the point at which the muscular axis of conduction tissue enters the fibrous insulating plane. Within the atrial component of the triangle of Koch, a layer of transitional cells interposes between the compact node, with its inferior
extensions, and the ordinary atrial working myocardium. Two areas of the ordinary atrial myocardium in the nodal approaches are then of significance in terms of ablation of the fast and slow pathways. Lesions destroying the fast pathway are placed in the atrial fibers at the anterior margin of the oval fossa, whilst the slow pathway is destroyed by lesions placed in the septal isthmus (Figure 27). The precise anatomic substrates for these pathways have still to be determined, but the orderly orientation of the ordinary atrial myocardial fibers is likely to play some role.

THE ANATOMY OF THE CIRCUIT FOR ATRIAL FLUTTER

It is now well established that the commonest type of atrial flutter, so-called Type 1 flutter, is the consequence of macro re-entry within a large circuit confined to the right atrium. The reciprocating wave passes counter-clockwise round this circuit, which uses the terminal crest for its descending limb, and the triangle of Koch and the anterior margin of the oval fossa as the ascending component. It is also possible that the circuit can extend round the vestibule of the tricuspid valve. Irrespective of the precise nature of its upper margin, however, the most crucial part of the loop is the so-called cavotricuspid isthmus between the mouth of the inferior caval vein and the hinge of the septal leaflet of the tricuspid valve. This inferior isthmus is the target for catheter ablation, which is now known reproducibly to abolish the abnormal rhythm.

This inferior isthmus has a complicated muscular arrangement (Figure 28). Previously described as a posterior structure, attitudinal examination of the heart shows that the area is located inferiorly within the right atrium. Confined posteriorly by the mouth of the inferior caval vein, the isthmus is bordered laterally
by the terminal crest swinging down past the venous orifice, the muscular crest being reinforced in most hearts by the fibrous Eustachian valve. As the terminal crest reaches the posterior part of the isthmus, it breaks up into a series of trabeculations, but the wall of the atrium is remarkably thin between the muscular bundles, giving this posterior part of the isthmus a distinctly membranous appearance. The middle part of the isthmus is also trabeculated, but it, too, can be more membranous in structure, particularly when there is an extensive diverticulum beneath the mouth of the coronary sinus. This diverticulum, previously considered to be the sub-Eustachian sinus, is located beneath the valve guarding the orifice of the coronary sinus, making it sub-Thebesian. The middle part of the isthmus then continues directly into its smoothest anterior component, which is the vestibule of the tricuspid valve. The muscular fibers of the wall are usually particularly well aligned in this anterior component, which turns superiorly to become continuous with the septal isthmus, this latter area also being the slow pathway into the atroventricular node (Figure 27). The specific character of the isthmus varies from heart to heart, and these variations are almost certainly of importance for ablation, since clinical experience shows that, in some patients, the circuit can be broken without construction of a complete line between its posterior and anterior boundaries. The only consistently smooth muscular area within the isthmus is the vestibular component, and this may well prove to be the optimal site for ablation.

ATRIAL STRUCTURE RELATIVE TO FIBRILLATION

Recent experimental work, notably that produced by Allessie and his colleagues in Maastricht, has shown the fibrillating atrial rhythm to be the consequence of multiple circling wavelets of activity. So as to perpetuate the fibrillatory activity, it is also now established that a critical area of atrial musculature must remain in electrical continuity. If the atrial walls can be compartmented so that the area of each unit thus isolated is insufficient to support the circling wavelets, then fibrillation ceases. This is the rationale of the surgical maze procedure. It is now established that similar mazes can be created by constructing linear lesions by means of catheter ablation. Even more recently, experience in the clinical arena has shown that paroxysmal atrial fibrillation can have a focal origin, usually from the mouths of the pulmonary veins at their entrance to the left atrium. The structure of the venoatrial junctions, therefore, have also attracted considerable recent attention. Knowledge of the overall muscular structure of the atrial walls can help markedly in selecting the appropriate maneuvers to abolish atrial fibrillation in the catheter laboratory.
As already emphasized, overall conduction through the atrial walls is governed by their geometry, and essentially both atriaums are muscular bags full of holes. Although for several years it was believed by some that specialized tracts of conduction tissue were responsible for atrial conduction in a fashion comparable to conduction through the His-Purkinje axis, it is now accepted that there are no insulated muscular tracts within the atrial walls. Indeed, criteria for the histological definition of such tracts, if they exist, were provided already by 1910, albeit within the German literature. Had attention been given to these excellent accounts, all of the controversy which surrounded the purported "specialized internodal tracts" could have been avoided. But, although there are no insulated tracts within the atrial walls, this does not mean that conduction through the walls is entirely uniform and that the sinus impulse passes radially. In fact, there is preferential conduction along the major muscle bundles demarcated by the holes in the walls, with further potential for more rapid conduction along rather than across those fibers which are oriented in parallel fashion. Thus, atrial conduction shows marked non-uniform anisotropy, this being dictated by the organization of the muscular fibers.

Within the right atrium, the major muscle bundles with parallel alignment of their fibers are the terminal crest, the rims of the oval fossa, the sinus septum between the mouths of the inferior caval vein and the coronary sinus, the vestibule of the tricuspid valve, and the pectinate muscles running into the atrial appendage (Figure 13).

The greatest potential for conduction between the atriaums is around the margins of the oval fossa, notably through the anterior interatrial groove. Indeed, the terminal crest inserts directly into the muscular infolding forming the anterior groove. It then continues into the anterior wall of the left atrium as Bachmann's bundle. This is the major route for left atrial activation. In addition to the immediate margins of the oval fossa, which are infoldings superiorly (Figure 20) and posteriorly, the inferior margin is another potential area for interatrial conduction. Additional discrete muscular bundles can cross through the superior interatrial groove, one of these being the structure identified by Wenckebach as an interatrial bundle. There are then further muscular strands which run from the walls of the coronary sinus and join the posterior wall of the left atrium (Figure 29). Within the floor of the oval fossa itself, however, there is little potential for interatrial conduction, since any muscular bundles are buried within the fibrous flap valve of the septum.

Figure 29
The epicardial layers have been removed to show the orientation of muscular fibers in the posterior atrial walls.
The holes within the left atrium are the orifices of the four pulmonary vein (Figure 30), the mouth of the atrial appendage (Figure 31), and the orifice of the mitral valve. There are prominent circumferential fibers extending round each of these holes, particularly around the mitral vestibule (Figure 29). The fibers around the pulmonary venous orifices extend for various distances along the pulmonary veins towards the pulmonary parenchyma, with the longest sleeve found around the left upper vein (Figure 31), and the next longest around the right upper vein. It is tempting to believe that these muscular sleeves may be significant in focal fibrillation, the more so since it is known that ablation in the upper veins proves curative in the majority of cases of paroxysmal fibrillation, albeit that some cases require ablation in the lower veins.

The dome of the atrium between the mouths of the pulmonary veins (Figure 29) is the thickest part of the entire atrial musculature. Even within this area, however, there is a marked alignment of muscular fibers, with longitudinal bundles spanning from the posterior to the anterior parts of the mitral vestibule (Figure 32).

Figure 30
The posterior wall of the left atrium is anchored by the entrance of one pulmonary vein at each of the four corners.

Figure 31
The extent of the atrial muscular fibers is shown relative to the left upper pulmonary vein. Note also the circumferential fibers around the mouth of the appendage, and the parallel array of fibers in Bachmann’s bundle.

Figure 32
The potential lines which could be constructed to prevent atrial fibrillation are shown relative to the structure of the left atrium.
LINEAR COMPARTMENTATION OF THE ATRIUMS

Clinicians are still determining the most appropriate lines for construction of a reproducible maze which will prevent atrial fibrillation. The experience of Kuck and his colleagues in Hamburg is still evolving, but they have found it advantageous to construct three relatively short lines to separate the right from the left atrium, and then to construct additional lines within the left atrium. Whether all lines are necessary remains to be established by increasing experience. The first right atrial line is constructed anteriorly from the mouth of the superior caval vein down to the anterior part of the vestibule of the tricuspid valve (Figure 33). This line divides the terminal crest as it extends to feed Bachmann’s bundle. The second line is constructed posteriorly, and runs from the mouth of the superior caval vein down to the orifice of the inferior caval vein (Figure 34). The third line is then placed across the cavo-tricuspid isthmus, and is the same as is created for cure of typical atrial flutter (Figure 35). Others seek to place lines across the atrial septum, but this seems less well founded anatomically, since interatrial conduction is largely round the margins of the oval fossa and through Bachmann’s bundle. Experience is also accruing to show that, in some instances, lines created solely within the left atrium are sufficient to prevent fibrillation. These lines can be placed individually around the pulmonary venous orifices, or a single line can be placed to separate the posterior wall of the atrium, incorporating the venous orifices, from the remainder of the left atrial wall (Figure 32). Additional lines can then be constructed as desired across the dome of the atrium, either parallel or at right angles to the atrial septum, or in both directions. Only experience will show which of these various lines are most efficient at preventing fibrillation. The anatomy is such, nonetheless, that there are multiple smooth areas within the atrial walls which lend themselves to the construction of linear ablative lesions.

Figure 33
The anterior intercaval line which can be constructed within the right atrium to produce part of the maze to prevent atrial fibrillation.

Figure 34
The posterior intercaval line, depicted by blue pinheads, which is part of the right atrial maze. The line ablating the cavo-tricuspid isthmus, shown by white pinheads, is also seen.

Figure 35
The cast is shown from beneath, revealing the extent of the line required to ablate the cavo-tricuspid, or inferior, isthmus.
CONCLUSIONS

The ever increasing experience of clinicians working in the catheterization laboratory is showing the importance of a thorough knowledge of cardiac anatomy. For this to be of most value, the anatomy should be displayed in the same fashion in which clinicians view the heart in their fluoroscopic screens. This means that the heart must be described, and analyzed, attitudinally. Thereafter, it is necessary to know the relationships of the various chambers within the cardiac silhouette, and the structure of their walls, including the disposition of the specialized conduction system. This is the information which, hopefully, is provided by this booklet and the videotape it accompanies.
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GLOSSARY

Anterior - towards the front of the patient
Buttress - a prominent bulge
Cavotricuspid - the area between the inferior caval vein and the hinge of the tricuspid valve
Confluent - joined together
Crest - a raised prominence, like the peak of a hill
Crux - the crossing point of the septal structures and the atrioventricular groove on the diaphragmatic surface of the heart
Diverticulum - an outpouching
Endocast - the profile of a cavity shown by filling it with a solid substance (e.g. silicone)
Flap valve - the fibrous partition which closes the interatrial communication
Hinge - the closing point of a structure, as in the hinge of a door
Inferior - towards the feet of the patient
Interposed - placed between
Isthmus - a confined area between two much more extensive areas
Lesion - a pathological abnormality
Luminal - the surface of a chamber or vessel closest to the cavity
Margin - the edge of a structure
Mediastinal - in the middle component of the thorax
Notch - an indentation
Parenchyma - the substance of an organ, as in the lungs or kidneys
Parietal - away from the septum
Pectinate muscle - a muscular structure like the tooth of a comb, found in the atrial appendages
Posterior - towards the back of the patient
Pouch - an excavated opening, as with the cavity in which the Kangaroo carries its young
Probe-patent - the arrangement in which it is possible to pass a probe between the flap valve and the rim of the interatrial communication
Pulmonary trunk - the major arterial trunk supplying the lungs
Ridge - a sharply raised linear prominence
Spine - the vertebral column
Superior - towards the head of the patient
Superficial - on the surface
Straddles - a structure which passes to both sides of another structure
Tributary - a branch, as in two streams joining together to form a river
Vestibule - the gateway from the atrium to its corresponding ventricle