Focus on the Atrial Structure
—Useful Anatomical Information for Catheter Ablation—

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Catheter ablation of atrial fibrillation (AF) has been making remarkable progress for the last decade. When manipulating the catheter in the procedure, we have to reconstruct the three-dimensional cardiac structure in our heads by using two-dimensional fluoroscopic image. The author, an interventional electrophysiologist, developed and proposed a new method for recognizing the cardiac structure by using human body sections.

In order to easily create practical cardiac images, the human bodies were cut sagittally, obliquely and coronally. In the sections obtained, the heart could be observed together with their surroundings within the thorax in the neutral position. The most important point is that the heart is observed without being removed from the body. This concept of the research is to recognize the heart as an object composed of many structures. It was useful for analyzing the mechanism of arrhythmia and to improve catheter technique and mapping systems.

(Key words: Atria, Catheter ablation, Anatomy, Electrophysiology, Clinical cardiac structurology)

Introduction

With the development of technology for electro-physiological procedures, the importance of understanding cardiac anatomy has increased in order to interpret the information obtained from the electro-anatomical mapping of the heart and to analyze the mechanisms of arrhythmias.\(^1\)\(^2\) It goes without saying that a large amount of anatomical knowledge concerning the cardiac anatomy has already been accumulated in various kinds of textbooks. Of course, this has provided us with very important information for imaging the cardiac structures;\(^3\) however this level of anatomical knowledge does not appear to be adequate for cardiologists, in particular, electrophysiologists, in order to give them a complete image of the cardiac structures. Why is this inadequate? This is because the anatomical information required by electrophysiologists is not just the name of the structures. They also need practical images of the structures which they can use in various kinds of clinical situations.

During the examination or treatment procedure, they always reconstruct the three-dimensional cardiac structure in their heads by using their imagination from the two-dimensional fluoroscopic images. They manipulate the catheters based on the reconstructed cardiac image. They have to be aware of the anatomical pitfalls in order to avoid any
complications associated with the procedure, and to obtain some clues in order to solve the electrophysiological problem. In order to obtain a satisfactorily useful image, it is necessary to slightly change the manner of representing human heart specimens. In this review, I present the practical cardiac anatomy for meeting the needs of that arise in clinical situations. In particular, I would like to provide electrophysiologists with useful anatomical information about the atrial anatomy related to electrophysiology, which will help them to obtain an appropriate three-dimensional image of the atrial structures when manipulating catheters. In addition, I will introduce new anatomical information and propose a new way of thinking about the cardiac structures.

**Sagittal section of the human body for observation of the right atrium**

*Internal aspect of the right half of the right atrium*

Figure 1 shows the aspects of the sagittal sections of the human body which are observed from left to right (a) and right to left (b). The specimens were made by cutting the human body along line ① in Figure 2, to observe the cardiac structures together with the surroundings. Line ① is 1 cm to the right of the center line (CL).
In Figure 3, the internal aspects of the right half of the right atrium (RA), superior vena cava (SVC), inferior vena cava (IVC) and left atrium (LA) are demonstrated. The junction between the SVC and RA is not clear macroscopically. The LA is located behind the RA and in front of the vertebrae. The right pulmonary artery (RPA) is on the LA and just behind the SVC.

In the RA, a large muscle bundle called the terminal crest (TC) is seen, descending from antero-superior to infero-posterior. The interatrial septum (IAS), which the RA and LA share, can be seen. It is very important to note that the lower edge of the IAS indicated by the red arrow is located a little high in the aspect of this section.

In the LA, the orifices of the right superior and inferior pulmonary veins (RSPV, RIPV) can be seen and are indicated by the solid yellow arrow. The RSPV goes forward and right-laterally to the SVC. On the other hand, the RIPV goes backwards. It is notable that the RSPV lies anterior to the RIPV, and not superior to it. The interostial region, which is the so-called “carina”, clinincally, protrudes forming a ridge-like structure. As shown in Figure 3, this specific structure goes downward vertically.

When looking at the outside of the heart, the RA is covered with a visceral pericardium (epicardium), which is a serous pericardium. The epicardium extends to the SVC and covers its lower part. It reflects at the root of the SVC as shown by the white arrow (pericardial reflection (PR)). The parietal pericardium and parietal pleura are fused and form a membrane. In this figure, the pericardial cavity (PC) and pleural cavity (PlC) can be observed clearly outside the heart. Further, the right and left phrenic nerves, which are not represented in this figure, descend in a fused membrane.

Terminal crest

In the RA chamber, there is the terminal crest (TC) which can be recognized as a large protrusion of the endocardial surface. It is a thick muscle bundle traveling down from the upper to lower parts of the RA anterior to the SVC as shown in Figure 3 and the diagram (Figure 4). The thickness of the upper part of the TC is larger than that of the lower part. The TC descends on the posterolateral wall of the RA, and reaches the edge of the IVC. It surrounds the IVC from the anterior side, with the characteristics of the structure changing from muscle to the valve. This is called the IVC valve (or Eustachian ridge). The IVC valve is often fenestrated, which is called a Chiari anomaly. It is reported that this anomaly is observed in 13.6% of cadaver hearts. Furthermore, it extends to the posterior side of the coronary sinus ostium (CSos) as the Thebesian valve (ThV). Figure 5 shows an oblique section of the human body, which was made by using a different cutting method in Figure 2. The change in the structure from the TC to the IVC valve is clearly represented. Moreover, the continuation from the IVC valve to the ThV can be observed.
The RA is divided into two parts by this muscle bundle; one is a smooth part and the other a trabeculated part. Anatomically, the area anterior to the TC, which is the trabeculated part, is defined as the RA appendage (RAA). On the other hand, the area posterior to the TC is called the sinus venarum (SV). In the trabeculated part (in RAA), there are many small muscle bundles branching from the TC (pectinate muscles (PM’s)), which travel downward in parallel as demonstrated in Figure 3. The wall between the PM’s is extremely thin as shown in Figure 6. Technically, the TC is derived from the sinoatrial orifice separating the right horn of the sinus venosus and primitive atrium. The beginning of the TC is located in the anterosuperior edge of the IAS. This specific point of the IAS is in the anterior wall of the atrium, where the TC connects with Bachmann’s bundle. This important anatomical relationship is illustrated in Figure 4. This point faces the pericardial transverse sinus.

Extension of atrial myocardium into superior and inferior vena cava

Usually, electrical activity can be recorded in the SVC because we all have SCV muscle (myocardial sleeve) extending from the RA. However, there are various types of myocardial sleeves. The manner of the muscle extension into the SVC varies from person to person. It is noteworthy to know that the myocardial sleeve does not always encircle the SVC. Some go up straight, but others extend upward in a spiral.

The atrial myocardial extension often reaches the orifice of the azygos vein. Further, since the level of

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Figure 4  Diagram of continuation of atrial muscle bundles. The continuation, TC, is represented in the diagram. AmFW: anteromedial free wall, LFW: lateral free wall, LTC: left terminal crest, TMB: transverse myocardial bundle, TC: terminal crest

Figure 5  Oblique section of the human body. The human body was cut along line in Figure 2. Internal aspect of both atria and their surroundings are clearly demonstrated. The continuation of TC, ER and ThV can be recognized easily.
the orifice is the same as that of the bronchial bifurcation, we can confirm the location of the upper limit of the myocardial sleeve in the fluoroscopic image. Accordingly, we should try to perform potential mapping in the SVC at least up to the same level as the bronchial bifurcation when examining the electrophysiological characteristics of the myocardial sleeve covering the SVC.

It is well known that some types of AF are provoked by repetitive electrical firing of the SVC muscle. In that case, we are required to create bidirectional conduction block between the SVC and RA by ablating the SVC muscle around the SVC-RA junction in order to abolish the AF. Histologically, this boundary can be recognized easily. However, it is very hard clinically to confirm the boundary between the SVC and RA in the fluoroscopic image.

On the other hand, there is no myocardial extension into the IVC. The boundary between the RA and IVC can be observed clearly as described below.

Extension of the IVC into the posterolateral wall of the RA

In the posterolateral wall of the low RA, there is a triangle-shaped recess indicated by the white arrow in Figure 3. This area may be regarded as a part of the posterolateral wall of the low RA. However, this structure is a continuation of the IVC. In other words, this area is a part of the IVC. The sides of the triangle are the borderline (junction) between the IVC and RA. Therefore, no myocardium could be found in this triangle-shaped area. Accordingly, theoretically we cannot pace this area and cannot record any excitation in this area. Clinically, we can detect tiny, fine, dull potentials in this area, but they are far field potentials.
My colleagues and I reported the histological characteristics of this specific structure located in the low posterolateral RA in autopsied hearts. We made serial sections of the low RA as shown in Figure 7a,b,c. A histological examination demonstrated that the retracted area had no myocardium.\textsuperscript{12)} It is notable that this triangle-shaped area is covered with pleura, not epicardium from the outside. There is the pericardial reflection along the sides of the triangle. On the other hand, the other part of the low RA wall is covered with epicardium, and atrial muscle can be seen. Electroanatomical mapping (voltage map) of the RA during sinus rhythm shows that the color of this area is grey, which means it is a “myocardium free area” anatomically and an “electrical silent area” electrophysiologically, despite it’s playing a role structurally as part of the RA wall.

This structure is an extension of the IVC into the RA. The mean height of the triangle is $17.6 \pm 6.6$ mm. Surprisingly, there are some cases with a big triangle. In such cases, the apex of the triangle is as tall as the His potential recording site.

This is a common structure, but it has not been described so far. This anatomical information is very useful in thinking about reentrant atrial tachycardia with the reentry circuit around the IVC such as lower loop reentry. Furthermore, injury of the triangle-shaped area is considered to cause bleeding into the pleural cavity (hemothorax), and not into the pericardial cavity (cardiac tamponade).

Right phrenic nerve

The right phrenic nerve (RPN) is a structure we have to note in order prevent injury to it during catheter ablation. This is demonstrated in a cadaver (Figure 8a). As shown in the figure, it goes down vertically, along the lateral side of the RA between the RSPV and SVC.\textsuperscript{14)} Strictly speaking, the right and left phrenic nerves descend between the parietal pericardium and parietal pleura. From the viewpoint of the anatomy, ablation in the SVC has some risk of RPN injury. On the other hand, ablation at the orifice of the RSPV might not be associated with a great risk. What we should note is that the right and left phrenic nerves descend together with the pericardiocophrenic arteries and veins. The pericardiocophrenic artery is a branch of the internal thoracic artery and the pericardiocophrenic vein is a branch of the brachiocepharic vein. RPN injury is considered to be associated with injury of these vessels.

Left phrenic nerve

The left phrenic nerve (LPN) is demonstrated in
Figure 7c  Histology of the low RA wall (3, 4).
No atrial myocardium can be seen at the posterolateral wall. This wall is not covered with epicardium from outside. At the ends (C, D) of the myocardium indicated by black arrow, pericardial reflection is observed. This area is diagnosed extension of IVC from the histological characteristics.

Figure 8  The right (a) and left (b) phrenic nerve (RPN and LPN).
The RPN descends just lateral to the SVC (a). On the while, The LPN descends over the LAA and the lateral free LV wall (b).
cadaver heart of Figure 8b. The LPN goes down along the left side close to the aortic arch and descends over the left atrial appendage (LAA) and the left ventricle. It is relatively clearly represented in this specimen. Usually, the LPN cannot be seen in autopsied hearts taken from the body, because it is located on the side of the parietal pericardium. However, we can observe the LPN in cadaver hearts because of pericardial adhesions. This is a specific case. Clinically, the LPN is a structure we have to be aware of during epicardial ablation on the left side of the heart.

**Sagittal section of the human body for observation of the right atrium (left → right)**

**Internal aspect of the left half of the RA**

Figure 9 represents the other half of the thorax opposite to the previous section. In this specimen, the halves of the TC, SVC, IVC, RA, IAS, LA, RPA and RMB are observed. Besides those structures, the tricuspid valve (TV) with the anterior, septal and posterior leaflets (A, S, PTL), right atrial appendage (RAA), coronary sinus ostium (CSos), IVC valve (Eustachian ridge (ER)), oval fossa (OF) and pericardial oblique sinus (POS) can be confirmed. To observe the internal aspect of the RAA, it is necessary to view the specimen slightly from the lower side. The color of the OF is a little different from that of the surroundings. Its morphology is round-shaped. In this specimen, we cannot observe the entire internal aspect of the left half of the LA. Only the left terminal crest (LTC), which runs obliquely from anterosuperior to posteroinferior in this figure, can be seen.

**Right atrial appendage (RAA) and RAA pocket**

As introduced above, the structure from the anterior RA to TC is called the RAA, which extends forward. Its apex turns a little upward to the left. When viewed from outside of the RAA, the RAA wall is composed of two parts; one is the anteromedial free wall (AmFW), which faces toward the ascending aorta, and the other the lateral free wall (LFW) (Figure 10). They are divided by a sharp ridge. This ridge can be observed clearly starting from the neighborhood of the SVC. Macroscopically, its starting point is very clear, but it terminates unclearly around the AV groove. The AmFW faces the ascending aorta (AAo) across the pericardial transverse sinus (PTS). On the other hand, the LFW faces the middle lobe of the right lung across the pericardial and pleural cavity. When viewing the internal aspect of the RAA, there is another muscle bundle, which is called the sagittal bundle (SB). As shown in Figure 11, the starting point of this structure is the same as that of the TC, the anterior edge of the IAS. This bundle descends toward the vestibule of
the tricuspid valve annulus (TVA) from this specific starting point. In its course, it crosses the ridge of the RAA around its middle portion. It is notable that the SB does not form the ridge of the RAA. We can recognize this crossing point as a bending point on the ridge of the RAA. I propose this specific point be called the “RAA saddle” (Figure 10).

The RAA ridge makes up a triangle shaped small pocket together with the TC and SB at the base of the RAA. This area is recognized as a small recess. Furthermore, the wall in this area is extremely thin. Due to these structural characteristics of the RAA, electrode catheters are easily conducted to this recess of the RAA, and there is the risk of causing a perforation. I propose this specific anatomical structure be called the “RAA pocket” (Figure 11).

In the selective angiogram of the RAA, this structure “RAA pocket” is demonstrated as a small dome at the base of the RAA (Figure 12). Accordingly, the RAA has two domes, a large apical dome and a small basal one. From this specific aspect, I propose radiologically the RAA structure be called “twin dome structure”.

Cavotricuspid isthmus (CTI), small cardiac vein and sinusoid in CTI

When viewing the specimen from the upper side, we can notice the important area between the IVC and TV annulus, which is called the cavotricuspid isthmus (CTI). Furthermore, the orifice of the small vessel called the left inferior phrenic vein (LiphV) is within this area (Figure 9). In the location of this
orifice, there is the risk of LIphV injury during catheter ablation of the CTI. Injury to this vessel results in bleeding into the retroperitoneal space.

The cavotricupid isthmus (CTI) is regarded as a target site for the ablation of isthmus dependent atrial tachycardia (AT). During this treatment, the CTI is ablated linearly from the TVA to the IVC to create bidirectional conduction block. The success rate of this ablation is very high. Indeed it is an established treatment. However, there are some tough cases in which we cannot make a complete linear, continuous and transmural legion for various reasons.16) My colleagues and I reported that the anatomy of the CTI seems to be deeply involved in the outcome of the ablation.

The region of the CTI belongs to the trabeculated part, and its surface is very rough. On top of that, one third of the population has a small cardiac vein (SCV) which runs in the atrial muscle along the CTI. Its venous flow drains into the coronary sinus. If a CTI ablation is performed in a case with a SCV, the linear ablation line crosses the SCV. In that case, it would be very hard to create a transmural legion around the SCV because of the cooling effect of the SCV. As shown in Figure 13, the atrial myocardium around the SCV is still viable even after the ablation.

Usually, the cardiac vessels, arteries and veins, are within cardiac adipose tissue. However, the SCV runs within the atrial myocardium. This is an extremely different circumstance than in the other vessels. The sinusoid is one of the important components within the CTI. It is a space filled with blood flow. With this structure, it is possible that it has the same cooling effect as the SCV.

Subeustachian pauch (SEP)

As described above, the surface of the CTI is very rough. In the CTI, there is a notable structure, called the subeustachian pouch (SEP) which often makes it difficult to perform ablation or understand the electrophysiological findings. In autopsied hearts, we often see various kinds of pouches in the CTI. The size and morphology differ from case to case. A single pouch is common, but a double pouch is somewhat rare. The most important thing we have to keep in mind is that there are some cases in which we cannot find any myocardium in the wall of the SEP. In those cases, the SEP works as a blocking area electrophysiologically whereby it may cause the development of double potentials in the CTI during the tachycardia.17) Strictly speaking, the turning of the excitation around this region in the CTI during the tachycardia would create double potentials.

Pericardial oblique sinus (POS)

The pericardial cavity behind the LA is called the pericardial oblique sinus (POS). It is very important to confirm the pericardial reflection (PR). In Figure 14 showing another autopsied heart, the line of the PR is indicated by the solid arrow. The visceral pericardium (epicardium) does not cover the LA roof, the area around the four PVs, or the backside of the SVC and RA. Further, there is a space in front of the LA, which is called the pericardial transverse sinus (PTS). The PTS is the pericardial cavity between the anterior wall of the LA and AAo.

Bachmann’s bundle

Bachmann’s bundle was reported first by Lewis et al. in 1914.18) In that paper, they demonstrated that
it was a muscle band connecting the right and left atria at the anterior interatrial groove. They did not describe its electrophysiological properties in the interatrial conduction system.

After that, Bachmann described this muscle bundle in 1916 and introduced its role in the cardiac conduction system. Since then, this structure has been called “Bachmann’s bundle” clinically.

Bachmann’s bundle (BB) is a flat muscle bundle which is located in the anterosuperior wall of the atrium connecting the right and left atrial myocardium. As shown in Figure 15, BB is just beneath the epicardium, facing the pericardial transverse sinus (PTS). This is located just behind the AAo as shown in Figure 4. Histologically, BB has characteristics of atrial myocardium.

Electrophysiologically, it plays an important role as an interatrial conduction pathway connecting both atria. However, its electrophysiological characteristics in humans still remain unknown.

Up to now, no researchers have demonstrated how this muscle band connects the atrial muscle of both atria. In other words, no researchers have demonstrated anatomically the relation to the conduction system in the right atrium and in the left atrium. That is why it is very hard to image this structure in the chest X ray film or fluoroscopic image, especially to image it in relation to the sinoatrial node (SN).

**Sagittal section of the human body for observation of the left atrium**

Internal aspect of the right and left half of the LA

**Figure 16** shows the aspects of the sagittal sections of the human body which are observed from left to right (a) and right to left (b). These specimens were made for the observation of the LA structure together with the surroundings by cutting the human body along line ② in **Figure 2**, which is 1 cm to the left from the CL.
Because the cutting line is in the middle of the LA, the internal aspect of the LA on both the right and left sides can be easily observed. Unlike the previous sagittal sections, we can observe the esophagus (Eso) just behind the LA, aortic root in front of the LA, and descending aorta (DAo) behind the Eso and pulmonary trunk (PT). In these sections, the superior and inferior vena cava and left and right ventricles (LV and RV) are invisible. The lower part of the RA can be seen in both specimens. Furthermore, the LA is located posterosuperior to the RA. The relation of the location between the LA and RA in these sections is a little different from that in the previous body sections.5)

In Figure 16b, the internal aspect of the left half of the LA, RA, aortic root and PT are demonstrated.
The LA is behind the aortic root, in particular the non-coronary aortic sinus (partially the left aortic sinus). There is a pericardial cavity called the pericardial transverse sinus (PTS) between the LA and AAo. Further, the pericardial oblique sinus (POS) described as above is just behind the LA. The aspect of the POS becomes visible clearly by pushing the posterior LA wall to the anterior side as shown in Figure 17. The black arrow indicates the pericardial reflection (PR). In this view, the aspect of the pericardial cavity (PC) and the relationship between the posterior wall of the LA (LAPW) and esophagus can be clearly understood. Notably, the esophagus is also very close to the coronary sinus ostium as well as the LAPW. Accordingly, there is the risk of esophageal injury with catheter ablation performed at a site close to the CSos. The edge of the IAS attaches to the middle of the non-coronary aortic sinus. This point is close to the right fibrous trigone (RFT).

**Left atrial appendage (LAA)**

The morphology of the left atrial appendage (LAA) differs from person to person. The LAA has a lobulated structure. Figure 18 shows the external aspect of the heart. We can also confirm from the outside that the LAA has many lobes. The morphology of the first lobe is quite different from that of the other lobes of the LAA. The distal part of the first lobe often bends and its tip turns backward. The LAA wall on the endocardial side is trabeculated and the wall thickness of the intertrabecular area is extremely thin as shown in Figure 19. Cardiac adipose tissue cannot be seen on the epicardial side of the LAA. The LAA orifice is oval shaped and its major and minor axes are 17.4+/−4.0 mm and 10.9+/−4.2 mm, respectively, in our study.

**Left terminal crest (LTC)**

When observing the internal aspect of the LA, the ridge runs posteroinferior to anterosuperior. There are the left superior and inferior pulmonary veins (LSPV, LIPV) on the upper (posterior) side of the ridge and the left atrial appendage (LAA) on the lower (anterior) side (Figure 20). The surface of the area on the lower side of the LCT is relatively rough because this area is derived from the primitive atrium (Figure 20, Figure 21a). This structure forms the border between the single embryonic pulmonary vein (primordial pulmonary vein) and primitive atrium in the fetal period. This is a homologous structure of the terminal crest (TC) of the RA, which is a structure forming the border between the RAA and sinus venarum (SV). The TC is derived from the sinoatrial orifice between the primitive atrium right and horn of the venous sinus in the fetal period. That is why I proposed to call this structure the “left terminal crest (LTC)”. Figure 19 shows the histology of the LTC. In this section, the LTC forms the border between the LAA and the LSPV.

The muscle thickness of the LA is usually considered to be less than 3 mm; however it is not uniform. It is known that the LTC contains relatively large and uniform muscular bundles along
the longitudinal aspect. These muscle bundles extend to the anterosuperior and posteroinferior walls. I propose this specific muscle structure in the anterosuperior wall to be called the “transverse myocardial bundle (TMB)”. Its muscle thickness can be more than 5 mm in some cases (4.5 ± 1.3 mm). It is very important to know that the LTC continues to the TMB. This continuation of the muscle bundle extends to BB and the TC of the RA. This aspect of the continuation is represented schematically in Figure 4. From the electrophysiological point of view, excitation originating from the sinus node is considered to conduct to the right and left atria along this atrial muscle bundle system (LTC-TMC-BB-TC system).

Translucent area (TA)

Furthermore, we can confirm that there is a thin walled area just beneath the TMB in the anterior wall of the LA (LAAW). The muscle thickness is less than 1 mm (0.9 ± 0.2 mm). A discontinuity of the wall thickness in the LAAW can be observed in all autopsied hearts without any organic heart disease. This is a normal structure. This area of the anterior wall of the LA is translucent as shown in Figure 22. I propose this specific round-shaped structure to be called “translucent area (TA)”. From the viewpoint of the electrophysiology, this sudden change in the muscle thickness has some possibility to cause a conduction block at the border due to an impedance mismatch.

Diverticulum of the left atrial anterior wall

In autopsied hearts, we often see a small recess on the endocardial side of the LAAW. Sometimes, it is also detected by 3DCT. The recess is located in the upper part of the LAAW adjacent to the IAS as
shown in Figure 21a. In this case, the recess is 5 mm in depth, and 6 mm in diameter. Histologically, the construction of the wall in the recess is the same as that in other parts of the LAAW. The thickness of the wall is very thin (Figure 21b). Notably, trabeculated atrial muscle can be observed in the wall of the recess. This aspect causes us to speculate that the LAAW including the recess is derived from the primitive atrium. Judging from the anatomical information above, the recess in the LAAW is
diagnosed as a diverticulum. The injury of the LAAW diverticulum would cause hemorrhaging into the pericardial transverse sinus. It is considered to be a noteworthy structure during catheter mapping in the LAAW.

**Figure 21a** The internal aspect of the LAAW (a). The left panel (1) shows the internal aspect of the left heart immediately after removing from the body. The right panel (2) reveals a part of the LAAW after fixation with 10% formalin. The recess is observed at the upper part of LAAW on the right side.

**Figure 21b** Histological examination of the recess. Trabeculation is seen in the recess, and this structure preserves the atrial construction. This recess is diagnosed as diverticulum. What we should be aware is that the wall of the diverticulum is extremely thin compared to other part of the LA.

**Left carina**
Unlike the relationship of the location between the RSPV and RIPV (**Figure 23**), the LSPV is located anterosuperior to the LIPV, and not anterior to the LIPV. Furthermore, the surface of the “carina”
between the orifices of the LSPV and LIPV is flat, and not ridge-like (Figure 20).

Ligament of Marshall (LOM)

When viewing the epicardial side of the LTC, a groove with a large amount of adipose tissue is observed between the LAA and LSPV and LIPV. Since the LCT is a folded muscle structure, it protrudes on the endocardial side, but retracts on the epicardial side. In the epicardial cardiac adipose tissue the ligament of Marshall (LOM) can be seen as shown in Figure 18. It is a remnant of the left superior vena cava as well as the vein of Marshall (VOM). In many cases, there is a myocardial sleeve around them, which connects to the LA muscle at several points. This muscular sleeve is an extension of the myocardial sleeve around the CS. Many autonomic nerve fibers and ganglia are observed around the LOM. From this anatomical aspect neighboring the LCT, catheter ablation performed on the endocardial side near the LCT has some influence on the autonomic nervous system. Sometimes, the sinus node artery (SNA) branching from the left circumflex coronary artery is in this tissue.

Cave of the left atrial roof and the right pulmonary artery

Figure 23 represents the internal aspect of the right half of the left atrium (LA), aortic root, pulmonary trunk (PT), coronary sinus ostium (CSos) and right atrium (RA). The RSPV and RIPV orifices and their ridge-like “carina” are clearly demonstrated.

We should note that the right pulmonary artery (RPA) is on the LA roof and goes over the LA roof horizontally from left anterior to right posterior. For this reason, we can notice in this figure that the LA roof protrudes a little into the internal LA cavity.

Generally speaking, in case the LA becomes dilated for some reason, the LA roof expands toward the upper side. At that time it is pushed by the RPA from the upper side as a result. From this relationship between the RPA and LA, the RPA affects the morphology of the LA, especially the LA roof. In this case, the LA roof is pushed from the upper side by the RPA.

Similarly, the LA also expands posteriorly as the LA dilates. Consequently, it is pushed by the vertebrae from the posterior direction.

Thebesian valve (ThV)

When viewing the ostium of the CS in Figure 5 and Figure 23, there is a valve whose name is the valve of the coronary sinus (Thebesian valve (ThV)). As is often the case, this valve is fenestrated as well as the IVC valve. That is called a “Chiari net”. There is some possibility that a catheter being manipulated in the RA can become trapped by this fenestrated structure.

Right lung injury

Figure 5 and Figure 23 contain important anatomi-
ical information about the location of the right lung. The right lung is located behind the LA posterior wall (LAPW). The LAPW is extremely close to the right lung. This relationship between the LAPW and lung on the right side is quite different from that on the left side.

From this aspect, there is considered to be some risk of right lung injury associated with catheter ablation of atrial fibrillation, especially catheter ablation of the LAPW on the right side. This finding could be observed and validated in another sagittal section of the body (indicated by the white arrow).

Left atrial roof and left atrial roof vein

From the aspect of the LA represented in Figure 23 and Figure 20, the LA roof can be regarded as the area connecting the superior wall of the LSPV and that of the RSPV. Furthermore, we can image that the morphology of the LA roof is oval-shaped. The “LA roof” is just a technical term used in the clinical field, but not a formal one in anatomy. It seems to have been discussed so far on the basis of each individual image. There is no definition of the LA roof. We might suggest that the anterior boundary is the TMB and posterior one is the pericardial reflection on the LAPW. The LA roof is often regarded as a target of catheter ablation of AF. However, there is an important structure in this area we should note.

In the LA roof, a small tubular structure can be accidentally detected in the 3-dimensional computed tomography (3DCT) during the preoperative examination for catheter ablation. We can confirm by using selective angiography that this structure is a vessel connecting the LA roof. If the catheter is inserted into this vessel selectively, angiography reveals its aspect, such as the course and blood flow draining into the LA. There are some cases in which the LA roof vein is occluded. As far as we have investigated, its origin remains unknown. In some cases it seems to originate from the mediastinum and in others from the right or left lung.

Anatomically, it can be seen in 8% of autopsied hearts (Figure 24) and has a venous structure histologically. I named this vein the “LA roof vein”. In the majority of cases, this vein arises from the LA roof on the right side. The mean diameter of its orifice is 3.3 mm, ranging from 1.5 to 5.0 mm. There is no myocardial sleeve around this vessel. It may safely be said that it does not have any arrhythmogenicity. In manipulating catheters around the LA roof, we should be careful of this tubal structure, because there are some cases in which the LA roof vein is not represented not only by 3DCT at the preoperative examination but also by LA angiography during the catheter ablation procedure. What we should note is that 3DCT does not represent the LA roof vein as it is, or represents it as a small recess like a diverticulum in some cases. LA roof vein injury caused by catheter entrapment would result in hemorrhaging into the posterior mediastinum or into the pericardial oblique sinus. We should take this unexpected structure of the LA roof into consider-
ation in order to avoid any complications associated with catheter manipulation.

Esophagus (Eso)

The black arrows in Figure 20 show the visceral pericardium (epicardium) free area.

The esophagus descends from the upper to lower part of the backside of the LA. If catheter ablation is performed in the LAPW in the cases with the esophagus going down just beside LIPV, there is some risk of esophageal injury, such as LA-Eso fistula, because the esophagus has no pericardium directly in contact.

Mitral isthmus (MI)

It is well known that reentrant atrial tachycardia (AT) with the excitation circling around the mitral valve annulus (MVA) often develops after catheter ablation of AF, especially PV isolation. This type of AT has a critical pathway between the LIPV and MVA, the so-called “Mitral isthmus (MI)”, as a part of the reentry circuit. Accordingly, theoretically we can abolish this tachycardia by making bidirectional conduction block in the MI with catheter ablation. However, it is very hard to obtain success in many cases. In those cases, additional catheter ablation in the CS is required to ablate the CS musculature.

The anatomy of the MI is a little different from the other parts of the posterior wall of the LA. This area is derived from the primitive atrium embryologically. Basically, the surface of this area is rough as shown in Figure 20 and Figure 21a. Furthermore, we often see muscle bundles going down toward the vestibule of the mitral valve across the middle of the MI. Branches of the left circumflex coronary artery cross this region is found in 46% of the clinical cases, according to our investigation. These findings make it difficult to perform catheter ablation in the MI. In our experience, the LA and CS muscular connection may be the most important factor causing catheter ablation failure in the MI.

Discussion

The cardiac structure has been investigated minutely for a long time by many dedicated anatomists. This cardiac anatomy has been regarded as an established scientific field. However, there seem to be some atrial structures whose details are indeterminate or inaccurate. Furthermore, there are some important cardiac structures which the anatomists have overlooked. It may be a little harsh to ask the anatomists to get the cardiac anatomical information essential for the electrophysiologists. It seems to be necessary that we take an approach in which we...
make use of detailed information on cardiac anatomy.

Generally speaking, the results of the basic research are double-checked, whereas this checking mechanism in the field of anatomy does not seem to work well compared to that used in other academic fields. Cardiac structures should be confirmed not only anatomically, but also with other approaches, such as radiologically, sonographically, histologically, embryologically and electrophysiologically.

In the clinical field, we always transform the two-dimensional fluoroscopic image to a three-dimensional structure by using anatomical cardiac information in our heads and manipulate the catheter in the reconstructed cardiac image by adding a time factor. This transformation process should be performed strictly based on the accurate anatomical cardiac information, whereas the structures of the heart including their surroundings are not always reconstructed accurately. This means that the transformation process does not always work appropriately.

This process should be established as a field of science. I have been trying to systematizing the new approach of anatomy for understanding of cardiac structure related to arrhythmia, and I have named this scientific methodology “Clinical Cardiac Structureology”.

Of course I believe that this methodology will provide us with much useful anatomical information and electrophysiological speculation. However, we must not discuss cardiac function easily by using this method, because the studied heart is electrophysiologically static. We should control ourselves strictly and not put too much emphasis on this approach and keep in mind the limitations. This methodology also needs to be combined with newly developed technologies for cardiac imaging, such as MDCT and MRI, to be refined.

Further anatomical investigation of the heart is needed to improve the accuracy and to elevate the quality of the discussion about cardiac structures. I hope that my pictures presented in this review will be helpful to electrophysiologists for understanding three-dimensional cardiac structure.

References

9) Christoffels VM, Moorman AFM: Development of the cardiac conduction system: Why are some regions of the heart more arrhythmogenic than others? Circ Arrhythm Electrophysiol 2009; 2: 195–207