Anatomy of the left atrium for interventional echocardiography

Siew Yen Ho1*, Karen P. McCarthy1, and Francesco F. Faletra2

The anatomy of the left atrium is reviewed with relevance to various interventional transcatheter procedures requiring manoeuvres within or passage through the left atrium. The component parts of the atrium—the atrial body with a vestibule, appendage, venous component, and the atrial septum—are described with emphasis on their spatial relationships to neighbouring cardiac and extra-cardiac structures. Normal variations are discussed for a better understanding of the anatomy so as to reduce the risk of potential complications during procedures.

Introduction

With the increasing use of transcatheter interventional procedures requiring access through the atrial septum and into the left atrium, understanding the anatomy of the left atrium has become crucial for improving procedural efficacy and safety. Left atrial anatomy is relevant to procedures such as ablation for atrial fibrillation (AF), focal atrial tachycardia, left atrial appendage closure, and mitral valve reconstruction. However, the key to accessing the left atrium is safe trans-septal puncture. In this short article, we review the overall anatomy of the left atrium, the structure of the left atrial appendage, the arrangement of the pulmonary veins, and the limits of the true atrial septum for safe crossing in relation to neighbouring structures. The anatomy of the patent foramen ovale (PFO) will not be included in this review, since it has already been the subject of a previous article in this journal.1

Location and structure of the left atrium

Being the most posteriorly situated of the cardiac chambers, it is only separated from the oesophagus by the fibrous pericardium. While the proximity of the oesophagus is advantageous for the echocardiographer, it increases the risk of complications for the arrhythmologist ablating along the posterior atrial wall (Figure 1). The left atrial body possesses a venous component which receives the pulmonary veins and a vestibule which surrounds the mitral orifice and it has a blind-ending pouch-like appendage. It shares the septum with the right atrium. All these components are without obvious demarcations except for the appendix which has an opening (the os) from the atrial body. The pulmonary veins enter the posterior part of the left atrial body with the orifices of left veins located more superiority than the right veins.

The walls of the left atrium are muscular and can be described as superior, posterior, left lateral, septal (or medial), and anterior, as suggested by McAlpine2 with the addition of posteroinferior wall. Its anterior wall lies behind the transverse pericardial sinus which, in turn, is immediately behind the aortic root. The coronary sinus with its continuation, the great cardiac vein, runs along the epicardial aspect of the postero-inferior wall (Figure 1). It occupies the left atrioventricular groove, but in the majority of hearts, it is not at the same level as the mitral annulus nor does it always run parallel to the mitral orifice.3 The coronary sinus is wrapped by its own muscular coat to varying extents and muscular continuity between the sinus wall and the left atrial wall is common.4 However, the free wall of the sinus is often thin and relatively unprotected.

Excluding the atrial appendage, the walls of the left atrium are fairly smooth on the endocardial aspect although of non-uniform thickness. Suggested by McAlpine2 with the addition of posteroinferior wall. Its anterior wall lies behind the transverse pericardial sinus which, in turn, is immediately behind the aortic root. The coronary sinus with its continuation, the great cardiac vein, runs along the epicardial aspect of the postero-inferior wall (Figure 1). It occupies the left atrioventricular groove, but in the majority of hearts, it is not at the same level as the mitral annulus nor does it always run parallel to the mitral orifice. The coronary sinus is wrapped by its own muscular coat to varying extents and muscular continuity between the sinus wall and the left atrial wall is common. However, the free wall of the sinus is often thin and relatively unprotected.

Excluding the atrial appendage, the walls of the left atrium are fairly smooth on the endocardial aspect although of non-uniform thickness. Viewed from inside the atrium, the walls are perforated by orifices of the pulmonary veins, atrial appendage, and the mitral valve. Thus, in-between the ipsilateral pulmonary venous orifices are the interpulmonary ridges. There is usually a prominent ridge in between the os of the atrial appendage and the left superior pulmonary venous orifice (Figure 1). It is recognized as a Q-tip sign on echocardiographic imaging. When prominent, it can be mistaken for a thrombus or atrial mass. Termed the posterolateral ridge, this is an infolding of the left atrial wall. In cross-section across its narrowest part, the profile of the fold is rounded in 75% of heart specimens, flat in 15%, and pointed in 10% with implications for catheter stability when ablating along the ridge (Figure 1). The fatty tissues on the epicardial side of this fold contain atrial arteries, nerve bundles, as well as the oblique vein of Marshall or its remnant that descends to join the coronary sinus. This vein is obliterated for the most part, but it remains patent as the persistent left superior caval vein which occurs occasionally as an isolated malformation in the normal population.
In a review of published papers, it was reported that AF thrombi were located in the left atrial appendage in \(~90\%\) of patients with non-rheumatic, making this finger-like extension of the left atrium of great strategic importance for stroke prophylaxis.\(^8\) On the normal radiographic cardiac silhouette, the appendage is seen on the left border between the left ventricle and the pulmonary outflow tract. The tip of the appendage can be in a variety of positions, lying over the pulmonary trunk, left anterior descending coronary artery, pointing posteriorly, or even towards the back of the aorta.

In human hearts, the left atrial appendage is characteristically a slender finger-like extension from the atrial body although it can also be stump-like. The external aspect of the finger shows multiple crenellations giving wide variations in number and arrangement of lobes or branches. Internally, the endocardial aspect is lined with muscle bundles of varied thicknesses like the pectinate muscles of the right atrium (Figure 2). However, the bundles are arranged in whorl-like fashion instead of being in an array, since the left atrium lacks the equivalent of a terminal crest. In between the muscle bundles, the wall is paperthin. The appendage communicates with the atrial chamber through a narrow oval-shaped orifice with the mean long diameter of 17.4 ± 4 mm and short diameter of 10.9 ± 4.2 mm measured on heart specimens.\(^9\) In some hearts, the endocardial aspect around the orifice can be associated with pits and troughs where the wall becomes remarkably thin.\(^9\)

A post-mortem study of resin casts from 220 left atrial appendages showed those from patients with AF to have larger volumes and orifices than those from patients in sinus rhythm.\(^10\) More recently, a study of post-mortem and explanted hearts revealed the left atrial appendage from patients with AF to have three times the volume of those in sinus rhythm.\(^11\) Furthermore, the endocardial surface was smoother and associated with more extensive endocardial fibroelastosis in those with AF. Such features could contribute to appendage dysfunction and predisposition to thrombus formation.\(^11\)

**Figure 1** (A and B) Sagittal sections showing the left side of the left atrium (LA). (A) The oesophagus (Eso) passing behind the posterior left atrial wall and a broad left-lateral ridge (double arrows). The left upper (LUPV) and left lower (LLPV) pulmonary veins enter the left atrium via a short common stem. In (B), the section passes through the orifice of the left atrial appendage (LAA) and the infolding of the ridge. The triangle indicates the carina or interpulmonary ridge between the upper and lower pulmonary veins. The great cardiac vein (gcv) runs underneath the left atrial wall. (C and D) Real-time three-dimensional transoesophageal echocardiography images viewing the pulmonary venous orifices en face. The interpulmonary and left-lateral ridges are indicated.
Figure 2  (A) This heart specimen displays the two atria after removal of the superior, posterior, lateral, and anterior walls leaving mainly the vestibular component leading to the mitral (MV) and tricuspid (TV) valves. The non-coronary (posterior) aortic sinus has also been removed to show the location of the aortic valve (Ao) immediately in front of the plane of the atrial septum. Pectinate muscles line the endocardial surface of the left atrial appendage (LAA). (B) This real-time three-dimensional transoesophageal echocardiography image shows a view closely corresponding to the heart dissection. The thin valve of the oval fossa (FO) lies on the left atrial side of the thicker rim which is made by the septum secundum (SS). The coaptation line of the mitral valve is oblique to the septal plane.

In terms of relationship of the os to important structures, it is worth noting that it is situated above the left atrioventricular groove which contains the circumflex artery and the great cardiac vein together with their branches. A recent study on cadavers revealed that the course of the left phrenic nerve and its accompanying pericardiophrenic vessels passed in the fibrous pericardium that was overlying the tip of the appendage in 59% and accompanying pericardiophrenic vessels passed in the fibrous pericardium that was overlying the tip of the appendage in 59% and over the neck of the appendage in 23% of hearts.12

The septal component

The plane of the atrial septum is oblique with the left atrium situated more posterior than the right atrium although this relationship could change in some abnormal situations such as severe scoliosis, left ventricular hypertrophy with rotation of the cardiac axis, or dextrocardia. When viewed from the right atrium, the septal aspect can be misleading because it gives the impression of an extensive septal component. Particularly hazardous to interventionists is the wall in the anterior portion of the septal aspect known as the aortic mound which lies immediately behind the aortic root. In reality, the site of the true septum is the area of the thin flap valve of the oval fossa and its apposition to the muscular rim (limbus) that surrounds it (Figure 2). In the majority of patients, the right atrial side shows a depression on the septal aspect surrounded by a rim that is raised to varying degrees of prominence (Figure 3). In ~18% of individuals, the rim is flat and blends into the fossa without clear distinction between the two structures.13 On the left atrial side, the thin fossa valve is usually indistinguishable from the parietal atrial wall apart from a small crescent-like edge that marks the site of its free margin or PFO, which is the last part of the valve to become adherent to the rim.

Although generally expected to be in the middle of the septal wall, the location and size of the oval fossa varies from patient to patient. Instead of the usual tautness, the valve may be floppy, aneurismatic, or contain fenestrations. The variations in size and location alter the proximity of its margins to important structures. Importantly, the anterior rim of an anteriorly situated fossa may lie immediately behind the aortic root and is a potential hazard for aortic perforation (Figure 3). The posteroinferior component of the septal aspect is the left atrial wall overlying the coronary sinus which runs on its epicardial aspect.

The ideal site for crossing the septum is through the thin valve of the fossa. In the right atrium, the muscular rim surrounding the fossa valve in the superior, anterior, and posterior margins is an infolding of the atrial wall with epicardial fat on the outside (Figure 3). In some patients, the epicardial fat may increase the thickness to nearly 2 cm in the normal heart. Thickness of >2 cm on non-invasive imaging is increasingly reported as indicative of lipomatous hypertrophy, with incidence up to 8% reported on echocardiography.14 Septal perforation performed through the rim not only increases the risk of inadvertently exiting the heart, but the thick tissues can reduce maneuverability of the catheter after entering the left atrium. Importantly, the anteroinferior part of the muscular rim leading to the right atrial vestibule extends to the triangle of Koch that contains the atrioventricular node of the conduction system (Figure 3). This area is related to the septal region of the mitral annulus on the left side.

Even with a trans-septal puncture through the fossa valve, the relationship of the fossa to the superior wall or roof of the left atrium, the orifices of the pulmonary veins, and the mitral valve are important considerations for interventional procedures. In cases where the fossa is situated more superiorly than usual, the puncture site could lead to the atrial roof. The location is comparable to crossing at the site of a PFO although the latter may also direct the catheter towards the anterosuperior wall of the left atrium. The roof is one of the most difficult parts of the atrial wall to view by echocardiography. Its position is too far from the transthoracic approach, so the quality of image in far field is suboptimal. Conversely, it is too close when a transoesophageal approach is used and the image of the wall simply disappears, requiring frequencies as high as 10 MHz for visualization (Figure 3).
After septal puncture, the orifices of the left pulmonary veins and atrial appendage are directly ahead. In contrast, the orifices of the right pulmonary veins are found to be adjacent to the plane of the atrial septum as displayed on the four-chamber cut (Figure 3). The best way of visualizing the pulmonary veins by echocardiography, however, is the real-time three-dimensional (3D) transoesophageal echocardiography (TEE). With this technique, the pulmonary veins can be imaged in an ‘en face’ view or in a long-axis view (Figures 1 and 3).

The plane of the mitral orifice is anteroinferior relative to the fossa and the distance of the fossa to the mitral annulus varies with the location and size of the fossa. The coaptation line of the mitral valve is oblique with respect to the atrial septum, and this relationship is relevant in the setting of percutaneous mitral valve repair using a clip device (Figure 2). To facilitate the positioning of the clip delivery system perpendicularly to the mitral leaflets, the puncture site should be in the posteriorsuperior part of the fossa. However, in cases where the fossa is situated more posteriorly than usual, there is the increased risk of entering the pericardial space.

The typical arrangement of four distinct pulmonary venous orifices is present in ~20–60% of subjects, but it is also common to find the presence of a short or long common venous trunk on the left side, and supernumerary veins on the right side. Where there are four pulmonary veins, the inferior venous orifices are situated more posteriorly than the superior venous orifices. The right upper pulmonary vein passes behind the junction between the right atrium and the superior caval vein, whereas the lower pulmonary vein passes behind the intercaval area. The transition between the atrium and vein is smooth. On the epicardial side, the veno-atrial junctional areas are covered with epicardial fat pads. Musculature of the atrial wall extends into the veins for various distances. Overall, the myocardial sleeves are thickest in the inferior walls of the superior veins and the superior walls of the inferior veins.

The atrial wall between the pulmonary venous orifices is smooth on the endocardial surface. The thickness of the myocardium, however, is not uniform as the wall thins out towards the venous orifices. Post-mortem measurements of the mid-portions...
transmurally have demonstrated the area between the superior pulmonary veins to be the thinnest, 2.3 ± 0.9 mm, with no significant difference between patients with and without AF, whereas the wall was thinner in the middle and between the inferior venous orifices in those with AF.\textsuperscript{17}

**Conclusions**

Owing to its location and relationship with other cardiac and extra-cardiac structures and other cardiac chambers, the anatomy of the left atrium is important in many percutaneous interventional procedures. The true atrial septum is the safest site for trans-septal puncture, but the operator should be aware of ‘normal’ variants that could render the procedure more challenging and increase the risk of complications. The cardiac structures on the left side of the septum and their proximity to the septum are important considerations. The atrial septum, endocardial ‘ridges’, the left atrial appendage, and the pulmonary veins are particularly relevant to imaging patients with AF. Real-time 3D TEE could play an increasing role in interventional procedures, as it has the ability to view these structures from different perspectives and display variations in anatomy.

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**References**