Muscular architecture of the mitral isthmus: anatomical determinants for catheter ablation

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This editorial refers to ‘The anatomical characteristics of three different endocardial lines in the left atrium: evaluation by computed tomography prior to mitral isthmus block attempt’ by Y. Cho et al., on page 1104

Early electrophysiological studies demonstrated the presence of an isthmus of conductive tissue in the low lateral left atrium (LA) during ablation of left free-wall accessory pathways.¹ These studies introduced the LA ‘isthmus’ concept—a site of intra-atrial conduction block that shows the latest atrial activation during sinus rhythm. Although this posteroinferior area of the lateral LA wall between the orifice of the left inferior pulmonary vein (PV) and the mitral annulus cannot be considered an anatomic entity, it is now termed by electrophysiologists as the LA isthmus, or mitral isthmus.

Linear ablation connecting the inferior margin of the ostium of the left inferior PV and the mitral annulus, particularly when complete linear block is achieved, appears to increase the success rate of catheter ablation in patients with atrial fibrillation (AF) and prevent macro-reentry around the mitral annulus or the left PVs.²³ However, the creation of mitral isthmus lesions by catheter ablation is technically challenging and may be associated with significant complications. Factors that make obtaining a complete, transmural, and permanent ablation line across the mitral isthmus difficult may be electrical as well as anatomical because of the variable and complex endocardial geometry of the LA posterolateral region. Other factors include the unpredictable thickness of atrial myocardium and the cooling effect of the circumflex artery at different locations of this atrial territory.

A better understanding of the anato-mechanical substrate is essential for developing a proper LA isthmus ablation strategy that can contribute to successful outcome. In a valuable anatomic study in 20 hearts, Anton Becker⁴ showed marked variability in the dimensions of the mitral isthmus with considerable differences in thickness of the LA myocardium at various levels and among different hearts. This study also showed the close anatomic relationship between the isthmus area and the great cardiac vein and the left circumflex artery. The mean distance between the left inferior PV and the mitral annulus ranged between 17 and 51 mm (mean 34.6 mm). During catheter ablation procedures, incomplete linear lesions may result in conduction delay and facilitate subsequent macro-reentrant tachycardias, which are usually persistent. Therefore, the variable thickness of the LA myocardial tissue is highly relevant to achieve an adequate transmural linear lesion across the isthmus. The study by Becker showed that the mean myocardial thickness of the mitral isthmus at the level of the orifice of the PV was 3.0 mm (range 1.4–7.7 mm). The wall thickness midway between the PV and the mitral annulus was 2.8 mm (range 1.2–4.4 mm) while at the mitral valve annulus it was 1.2 mm (range 0–3.2 mm).⁴ In contrast, a more recent histological examination revealed that the thickest atrial wall was midway between the mitral annulus and the left inferior PV with tapering at either end of the isthmus.⁵ Wittkampf et al.⁵ have suggested that the muscle sleeve around the coronary sinus and the close anatomic proximity of the circumflex artery are the two major anatomic determinants for the creation of mitral isthmus conduction block. Atrial arteries fully embedded in atrial myocardium and closer than 5 mm from the endocardium are likely to be damaged by transmural lesions. In addition, local cooling mediated by atrial arteries and veins may protect the surrounding LA myocardium, preventing the formation of transmural lesions by radiofrequency energy applications and consequently making it difficult or impossible to create conduction block through the mitral isthmus.

Also relevant was the description by Wittkampf et al.⁵ of small crevices close to the base of the LA appendage. In a recent study of the posterolateral LA wall, we found in 28% of the hearts near-parallel muscle bundles separated by crevices of thin atrial wall between the inferior margin of the left PVs and the vestibule of the mitral valve, giving the area a ladder-like appearance on transillumination⁶ (Figure 1). In 16% of our specimens, the bundles were less obvious but the endocardial surface was indented with crevices and pits of various sizes and shapes. Histology confirmed that the atrial myocardium in the pits and crevices was extremely

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thin (mean 0.5 ± 0.2 mm). Crevices or pouches in this area may entrap the tip of the ablation catheter, potentially leading to excessive tissue heating with an increased risk of isthmus perforation and tamponade. These anatomic observations can be explained by the regional differences in orientation and thickness of the LA myocardial fibres. On the posterior wall, we found that the septopulmonary bundle often bifurcated to become two oblique branches. The leftward branch fused with, and was indistinguishable from, the circumferential fibres of the anterior and lateral walls, whereas the rightward branch turned into the posterior septal raphe. Often, extensions from the rightward branch passed over the septal raphe to blend with right atrial fibres and others towards the septal mitral valve annulus, forming a line that marked an abrupt change in subendocardial fibre orientation. The septoatrial bundle also passed leftward, superior, and inferior to the mouth of the atrial appendage to reach the lateral and posterior walls. Some of these fibres encircled the mouth of the LA appendage and continued into the pectinate muscles connecting with the vestibule of the mitral valve, forming extra-appendicular muscular bundles in 28% of the hearts.6

The elegant study of Cho et al.7 published in this issue of Europace, and previous clinical studies demonstrated that anatomic information can be obtained with current multislice computed tomography imaging reconstructions of the endocardial aspect of this posterolateral area of the LA.8,9 These studies included patients with and without AF, and demonstrated considerable variations in length, thickness, and configuration of the LA isthmus, including the presence of pouches, ridges, cord-like structures, and diverticula. These observations emphasize the importance of a better understanding of this atrial structure and its vicinity in order to facilitate ablation procedures and prevent serious complications. A recent electrophysiological and anatomic study demonstrated that patients with incomplete isthmus block were more likely to have a pouch at the isthmus (40 vs. 9%), a greater isthmus depth (8.1 ± 4.2 vs. 5.7 ± 3.4 mm), and a higher prevalence of an interposed circumflex artery between the coronary

**Figure 1** (A) Opened left atrium and left ventricle to show the extensive smooth-walled venous component. The septal aspect of the left atrium shows the crescentic line of the free edge of the flap valve (black dotted line) against the rim of the oval fossa. Note the extra-appendicular posterior pectinate muscles (PM) or ‘remnant’ PM, extending inferiorly from the orifice of the left atrial appendage (LAA) towards the vestibule of the mitral valve (MV). (B) In this specimen, the endocardium has been removed to show the arrangement of the myocardial strands of the septopulmonary bundle and septoatrial bundle around the left pulmonary veins and left lateral ridge to demonstrate the non-uniform myocardial thickness of the left lateral atrial wall to the vestibule of the MV. (C and D) (transillumination) Endocardial left atrial wall in a post-mortem heart specimen showing a prominent left lateral ridge, extending to the inferior margin of the left inferior pulmonary vein (LIPV). Note in (C) (black arrows) and (D) the ‘remnant’ pectinate muscles extending inferiorly from the LAA and pulmonary veins toward the vestibule of the MV and note the thinnest muscular wall in between the muscular trabeculae. (E) Sagittal histological section of the mitral isthmus stained with Masson trichrome to illustrate its anatomic relations with the great cardiac vein (GCV) and the left circumflex artery (LCx). Note the pectinate muscles, where the left lateral and posterior atrial wall becomes thinner (crevices). LIPV, left inferior pulmonary vein; LSPV, left superior pulmonary vein; RIPV, right inferior pulmonary vein, RSPV, right superior pulmonary vein; LV, left ventricle; MV, mitral valve.
sinus and the mitral isthmus (60 vs. 20%) compared with patients with isthmus block.\textsuperscript{10}

It has been shown that LA muscular bundles play an important role in the formation of LA flutter after PV isolation and could be identified as a conduction block line in patients during sinus rhythm.\textsuperscript{11,12} The application of anterior LA linear lesions, which pass near the PVs and join the mitral annulus in addition to the PV isolation, improved the long-term success of AF ablation preventing arrhythmia recurrence.\textsuperscript{13} In the anterior LA wall, the muscular architecture showed fibres taking origin from the septoatrial bundle. The fibres of this bundle ascended obliquely from the anterior interatrial raphe and combined with longitudinal fibres arising from the vestibule. They passed the posterior aspect of the LA between the left and right PVs, blending with longitudinal or oblique fibres of the septopulmonary bundle from the subepicardial layer.

Anatomic examination of the area between the right inferior PV and the mitral annulus, which was referred by Chiang et al.\textsuperscript{8} as ‘medial isthmus’, demonstrated that this area was longer and included more ridges than the ‘lateral isthmus’. In their study, Cho et al. also examined the anatomic architecture of two anterior endocardial lines connecting the mitral valve annulus with the right superior PVs (named ‘antero-medial’ isthmus line) and the left superior PVs (named ‘antero-lateral’ isthmus line). Computed tomography and post-mortem examination demonstrated that myocardial thickness was the greatest at the antero-lateral line. Interestingly, ridges, cord-like structures, and diverticula were more frequently found at the antero-medial line.\textsuperscript{7} These features may relate to the transmural muscular architecture of this area and reflect the complexity of the ablation attempts. We congratulate Cho et al. for their exhaustive anatomic description of this region. However, the anatomic concept of the mitral isthmus is ingrained in the literature and this term should not be used for other lines involving the PVs and mitral annulus. In our opinion, the term ‘left atrial isthmus’ or ‘mitral isthmus’ should be limited to the postero-lateral area of the LA bounded superiorly by the orifice of the left inferior PV and inferiorly by the mitral annulus involving the vestibule of this valve.

In summary, ablationists should be mindful of the non-uniform atrial myocardial thickness when performing continuous endocardial lines across the mitral isthmus and/or lines connecting anteriorly the PVs with the mitral annulus. A potentially thin atrial wall, the variable endocardial architecture and the interposed coronary artery between the coronary sinus and the mitral isthmus should be taken into consideration during the procedure. Non-invasive description of the mitral isthmus anatomy by Cho et al. using multislice computed tomography helps to characterize these anatomic determinants that may influence the efficacy and safety of AF ablation.

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**References**