# Mitral isthmus line: anatomical aspects relevant to linear catheter ablation

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## SUMMARY

Atrial Fibrillation (AF) is a common cardiac arrhythmia for which Pulmonary Vein (PV) isolation remains a mainstay treatment. Several linear ablation lines have been suggested to improve the efficacy of PV isolation. The mitral isthmus line/region lies between the left inferior PV and mitral valve annulus within the left atrium and used for targeting non-PV triggers during AF. Unfavorable anatomy along this line leads to incomplete ablation and recurrence of AF. The aim of this study is to provide anatomical data of mitral isthmus region and its implications for linear catheter ablation procedure. Total fifty formalin-fixed cadaveric hearts were examined. The mitral isthmus line was evaluated for its length, shape and presence of any structures.

The mitral isthmus line length was not uniform with ranges between 21.05-34.62 mm (mean-28.55 ± 3.12 mm). In 40% of studied hearts, a high amount of anatomic heterogeneity was present in this region, with undesirable structures like crevices (28%) and diverticula (12%). These structures had thinner walls compared to the surrounding atrial wall. The mitral isthmus line had concave shape in majority of cases (98%). This study concludes that a high amount of anatomical variability and barriers are present in along the mitral isthmus line. This could make it difficult to achieve complete block during ablation with pertaining risks of complications. Individualized strategy for ablation after studying the local anatomy is suggested to improve procedural outcomes.

**Key words:** Atrial fibrillation – Catheter ablation – Mitral isthmus – Left atrium – Anatomy

## INTRODUCTION

Atrial Fibrillation (AF) is the most common type of arrhythmia encountered in clinical practice. The mechanism of AF is complex. In paroxysmal AF the ectopic foci majorly originate from the Pulmonary Veins (PV) (Chen et al., 1999). Pulmonary vein isolation remains a mainstay for treating drug-refractory AF in these cases (Chen et al., 1999; Calkins et al., 2012; Oza et al., 2023). However, PV isolation is not fully effective and has high recurrence rate in patients with persistent AF (Pappone et al., 2001; Kirchhof et al., 2017). In persistent and long-standing persistent AF, electroanatomic substrate modification of the atrial tissue occurs, which leads to foci originating from several non-PV triggers (Haïssaguerre et al., 2005; Tilz et al., 2010). Subsequently several adjuvant linear lesions have been

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proposed by electrophysiologists to increase the efficacy of catheter ablation procedures (Calkins et al., 2012). Of the several proposed lesions, only mitral isthmus line and roof line ablation is commonly performed in adjuvant to PV isolation (Hocini et al., 2005; Jais et al., 2004). The mitral isthmus line is located in the lateral part of the left atrium between the left inferior PV orifice and the mitral annulus. Mitral isthmus ablation has shown favorable results (Jais et al., 2004). This may be due to impact of mitral isthmus ablation on multiple factors like substrate modification, elimination of ectopic triggers, atrial debulking, cardiac autonomic system modification and prevention of macro reentry around mitral valve annulus (Wong et al., 2012). In practice, however, creation of complete mitral isthmus block is difficult, as mitral isthmus anatomy is non-uniform with high variability. Presence of unfavorable anatomical structures in the region leads to incomplete mitral isthmus ablation resulting in recurrence of AF (Becker et al., 2004; Chiang et al., 2006). Despite high usage, few cadaveric and histological studies have evaluated mitral isthmus. Hence, we aimed to study the mitral isthmus anatomy in gross specimens with special focus on unfavorable structures.

## MATERIALS AND METHODS

Total fifty formalin-fixed adult cadaveric heart specimens irrespective of age, sex and race were collected from the Department of Anatomy for this study. Cadaveric hearts with visible anatomical damage or pathological conditions were excluded. The research protocol for conducting this study was approved by the Institutional Ethics Committee of GMERS Medical College and Civil Hospital, Sola, Ahmedabad. Reference no. – GMERSMCS/IEC/44/2022.

All the hearts were dissected from the thorax along with proximal parts of the great vessels like vena cavae, pulmonary arteries, pulmonary veins and ascending aorta. The heart specimens were cleaned properly and were selected randomly for the study.

A horizontal and two vertical incisions were made in the posterior wall of the left atrium between the left and right sided PV. This flap-like incision was turned inferiorly, and blood clots present inside the left atrium were removed.

All the parameters were studied from the endocardial aspect. For morphometric analysis and linear measurements, a ZHART Digital Caliper 150 mm was used. This device had an accuracy of 0.02 mm.

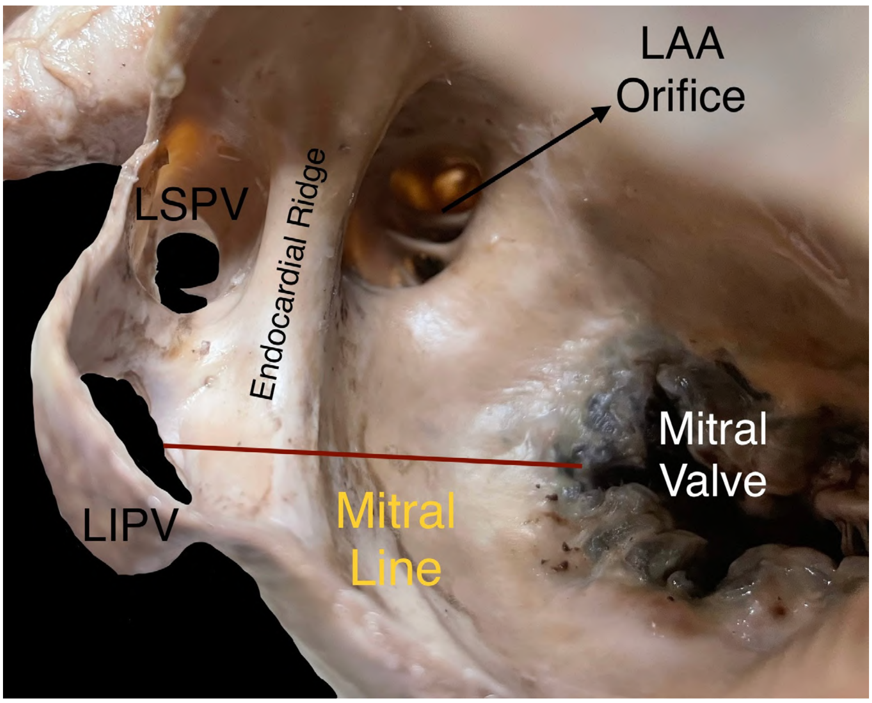


**Fig. 1.-** Mitral isthmus line inside the left atrium (LSPV- Left Superior Pulmonary Vein, LIPV- Left Inferior Pulmonary Vein, LAA- Left Atrial Appendage).

The mitral isthmus line was the shortest line between the inferior margin of the ostium of the left inferior pulmonary vein and the mitral valve annulus (Figure 1). After defining the line, its length was measured by using the electronic caliper. This was followed by gross examination of the mitral isthmus line by checking the presence of any structures and variability along its length. Relative roughness and smoothness of the line along with its shape was also assessed.

The mean values along with standard deviation were determined using Microsoft Excel.

## RESULTS

The mean length of the mitral isthmus line was 28.55 ± 3.12 mm. In 60% of cadaveric hearts of our study, the mitral isthmus line was found smooth. In the remaining 40% of hearts, the mitral isthmus line had rough surface with different structures like crevices in 28% and diverticula in 12% of cases. Figures 2 and 3 show the unfavorable structures found along the line. In most of the cases, the mitral isthmus line was found to have a concave curvature (Table 1).

We also noted on transillumination that crevices and diverticula had thinner walls and deficient myocardium in comparison to surrounding atrial wall.

## DISCUSSION

The Mitral Isthmus was first defined by Luria et al. (2001) as a zone of conductive tissue. Initially, endocardial ablation was performed at this site to treat perimitral macroreentrant flutter. Jais et al. (2004) later showed that ablation at the mitral isthmus along with PV isolation has better clinical outcomes in patients of persistent atrial fibrillation compared to PV isolation alone. Very few cadaveric studies have evaluated the anatomy of this region. We noticed that the mitral isthmus line extended between the Left Inferior PV and the mitral valve passing over the endocardial ridge. The heterogeneous myocardium at the PV-Left atrial junction is a common zone for generation of ectopic foci resulting in AF (Sánchez-Quintana et al., 2012). Also, autonomic ganglionated plexi known to play role in AF generation are located near the mitral isthmus in posterior wall of left atrium (Armour et al., 1997). The endocardial ridge houses the Ligament of Marshall, which is an embryological remnant. The Marshall bundle present here has shown to be both an electrical as well as autonomic conduit, playing role in AF pathogenesis (Doshi et al., 1999; Hwang et al., 1999). Hence, ablation at the mitral isthmus could help target all the above-mentioned sites resulting in high success rates.

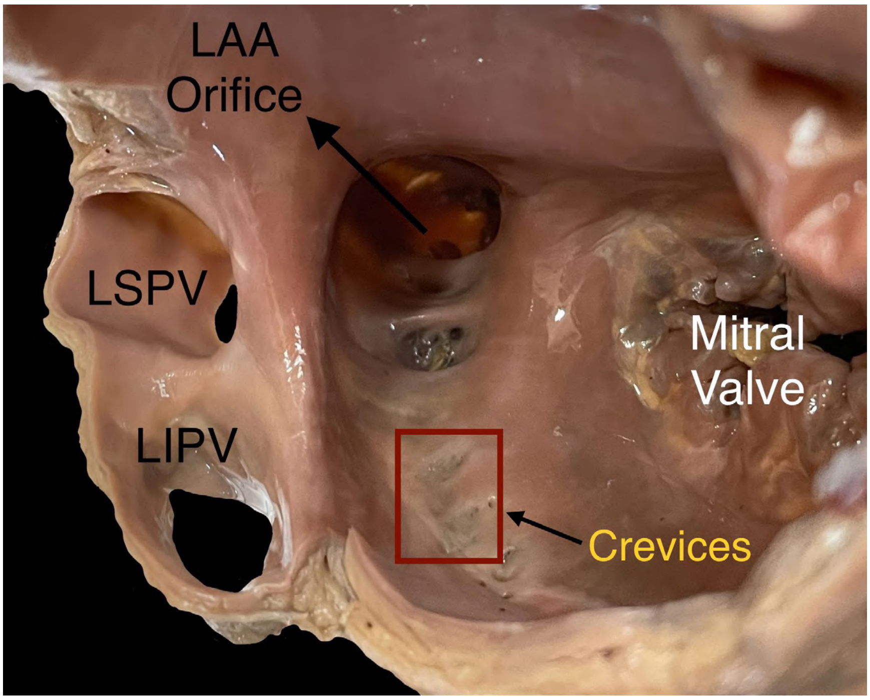


**Fig. 2.-** Multiple crevices in the mitral isthmus region.

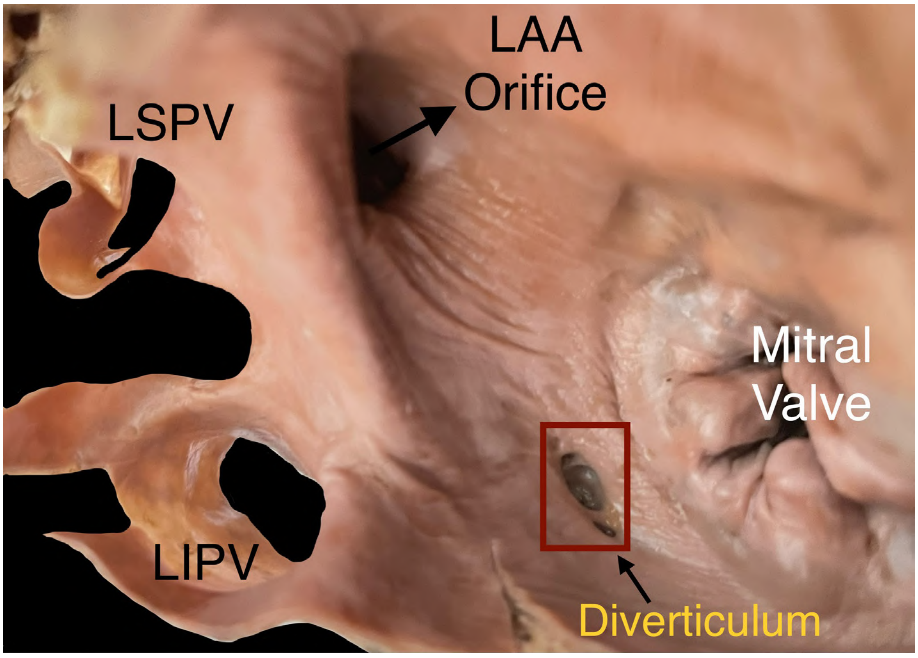


**Fig. 3.-** Diverticulum in the mitral isthmus region.

**Table 1.** Morphological and morphometric data of mitral isthmus line.

| Parameter | | Results |
|---|---|---|
| Length of Mitral Isthmus Line (mm) | Mean ± SD | 28.55 ± 3.12 |
| | Maximum | 34.62 |
| | Minimum | 21.05 |
| Rough surface of Mitral Isthmus Line | | 40% |
| Presence of Unfavorable Structures | a. Crevices | 28% |
| | b. Diverticula | 12% |
| Shape of Mitral Isthmus Line | | Concave – 98% |

In our study, the mean length of the mitral isthmus line was 28.55 ± 3.12 mm. Similar results were seen in study by Holda et al. (2017). In the cadaveric studies performed by Becker et al. (2004) and Wittkampf et al. (2005), mitral isthmus line lengths were longer. Table 2 shows the mean mitral isthmus line lengths among different cadaveric studies. The lengths of mitral isthmus line in CT-based (Computed Tomography) studies performed by Cho et al. (2012) and Cismaru et al. (2015) on patients of atrial fibrillation were 36.4 ± 8.6 mm and 29 ±11.2 mm. Nonetheless, remarkable variability in the length of the mitral isthmus exists. In our study, mitral isthmus length ranged between 21.05-34.62 mm. We suggest prior estimation of mitral isthmus length to avoid unwanted ablation of surrounding structures.

We observed a high amount of anatomic heterogeneity within the mitral isthmus region. Differently arranged muscular and membranous structures were present in 40% cases. Crevices were

**Table 2.** Mitral isthmus line length across different cadaveric studies.

| Study | Mitral Isthmus Line Length (Mean ± SD in mm) |
|---|---|
| Becker et al. (11) | 34.6± 10.0 |
| Wittkampf et al. (19) | 35.0± 7.0 |
| Holda et al. (18) | 28.8 ± 7.0 |
| Present Study | 28.55 ± 3.12 |

seen in 28% cases, followed by diverticula in 12% cases. Clinical studies have found these structures responsible for incomplete mitral isthmus lesion. This was proarrhythmic and lead to worse outcomes (Knecht et al., 2008). Holda et al. (2017) reported such structures in 34.5% cases, whereas initial study by Wittkampf et al. (2005) found small crevices in 94% of all studied specimens. These structures are said to be remnants of pectinate muscles in the LAA (Left Atrial Appendage) (Holda et al., 2017). Their presence during ablation could cause entrapment of catheter tip leading to difficulty in forming complete transmural lesions. Previously, crevices along the mitral isthmus line have been shown to cause reduced efficiency in delivering energy (Wittkampf et al., 2005). To overcome this, a greater amount of energy may be required for proper ablation. On the contrary, we observed that these structures have much thinner walls compared to the normal left atrial wall. This was also reported in study by Cabrera et al. (2012). Application of a higher amount of energy would result in perforation of the atrial wall leading to serious complications like cardiac tamponade. This creates a double-edged sword while attempting ablation. In addition to the unfavorable structures, the mitral isthmus line also had concave shape in 98% of the studied specimens. Concavity and increased depth of the region decreases the catheter stability and furthers difficulty in ablation (Chiang et al., 2006; Cho et al., 2012; Yokokawa et al., 2011).

Although mitral isthmus is frequently targeted for linear ablation, a high amount of anatomical variability makes it difficult to achieve complete block with pertaining risks of complications. Thus, pre-evaluation of mitral isthmus anatomy should always be done before ablation. Development of individualized strategies based on variations found can significantly improve the outcomes of mitral isthmus ablation.

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