Catheter Ablation of the Superolateral Mitral Isthmus Line
A Novel Approach to Reduce the Need for Epicardial Ablation

BACKGROUND: The mitral isthmus is a critical part of perimital reentrant tachycardia, as well as an important substrate of persistent atrial fibrillation. Deployment of an endocardial mitral isthmus line (MIL) with the end point of bidirectional block may be challenging and often requires additional epicardial ablation within the coronary sinus.

METHODS AND RESULTS: The study population comprised 114 patients with perimital flutter who underwent de novo ablation of an MIL. The initial 57 patients (group A) underwent catheter ablation using a novel superolateral MIL design, connecting the left-sided pulmonary veins with the mitral annulus along the posterior base of the left atrial appendage visualized by selective angiography. The next 57 patients (group B) served as a control group and underwent ablation using a conventional MIL design, connecting the left inferior pulmonary vein with the mitral annulus. Bidirectional block was achieved in 56 of 57 patients in group A (98.2%) and 50 of 57 patients in group B (87.7%; P=0.06). Deployment of a superolateral MIL required significantly less ablation from within the coronary sinus (7.0% versus 71.9%; P<0.01). Predictors for unsuccessful bidirectional mitral isthmus blockade were the need for epicardial ablation from within the coronary sinus (7.0% versus 71.9%; P<0.01) and the total length of the MIL (29.3±6.35 mm versus 40.8±7.29 mm; P=0.005). A higher rate of pericardial tamponade was observed in group A (5.2% versus 0%; P=0.24).

CONCLUSIONS: The superolateral MIL is associated with a high acute success rate to achieve bidirectional block using endocardial ablation only with minimal need for epicardial ablation from within the coronary sinus.

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Catheter ablation of atrial fibrillation (AF) is an established treatment option for symptomatic AF and left atrial tachycardia (AT). Interventional therapy focusing on electric isolation of the pulmonary veins (PVI) has demonstrated encouraging results in paroxysmal AF, while catheter ablation for persistent AF and AT remains challenging. A variety of strategies have been proposed to address this shortcoming by expanding catheter ablation for persistent AF beyond PVI alone. One of these strategies, deployment of a mitral isthmus line (MIL), continues to be a key tool for the management of persistent AF and subsequent AT. It has been hypothesized that MIL ablation targets additional arrhythmogenic triggers arising from the ligament of Marshall, affecting the intrinsic cardiac autonomic nervous system and eliminating local reentry while preventing perimital macroreentry. Furthermore, electric isolation of the left atrial appendage (LAA) has recently been proposed as an adjunct approach to improve long-term outcomes in patients with persistent AF. A prerequisite for LAA isolation in many cases is sustained conduction block of the MIL.

**WHAT IS KNOWN?**
- Deployment of a conventional mitral isthmus line connecting the mitral annulus and the ostium of the left inferior pulmonary vein is technically challenging and regularly requires not only extensive endocardial ablation but frequently epicardial ablation from within the coronary sinus.

**WHAT THE STUDY ADDS?**
- The superolateral mitral isthmus line targets the mitral isthmus at its thinnest portion where bridging of an endocardial linear lesion by muscular sleeves encircling the coronary sinus is unlikely.
- A high acute success rate of bidirectional block using endocardial ablation only can be achieved with minimal need for epicardial ablation from within the coronary sinus. Predictors of unsuccessful bidirectional mitral isthmus line blockade are the need for epicardial ablation and a greater length of the mitral isthmus.
- Compared with conventional mitral isthmus ablation, the incidence of pericardial effusion may be higher.
Deployment of an MIL remains technically challenging and regularly requires not only extensive endocardial ablation but frequently epicardial ablation from within the coronary sinus (CS). Achieving bidirectional conduction block is imperative because incomplete block is associated with an increased risk for iatrogenic left AT. Nonetheless, reported acute success rates vary widely from as little as 32% to 92%.12–17

Difficulties in creating sufficient lesion depth across the mitral isthmus can be attributed to specific local anatomic features. Myocardial thickness varies considerably along its horizontal and vertical course, with greatest tissue depth along the pulmonary vein ostium and the inferior portion of the mitral isthmus. Myocardial thickness tapers down toward the mitral annulus and the superior aspect of the mitral isthmus.18,19 Furthermore, myocardial sleeves around the CS extending toward atrial myocardium may remain unaffected by endocardial lesion delivery, precluding successful block across the mitral isthmus. Importantly, as the CS extends distally, the prevalence of muscular sleeves decreases notably.18

Therefore, in this study, we sought to investigate the feasibility and safety of an alternate ablation line design targeting the mitral isthmus at its superolateral aspect, where the atrial myocardium is thinnest and the prevalence lowest that myocardial sleeves encircle the CS.

METHODS

Study Population
The current study is based on an observational single-center analysis. The study included 114 consecutive patients with perimital reentrant tachycardia during a first or repeat ablation procedure for symptomatic persistent AF. None of the patients had undergone prior ablation along the mitral isthmus. Only if AF converted to an AT during PVI or complex fractionated atrial electrogram ablation or if patients presented with AT after prior PVI or complex fractionated atrial electrogram ablation, a MIL was deployed after entrainment confirmed perimital reentry as the underlying tachycardia mechanism. Patients were included between January 2009 and December 2011. Exclusion criteria were severe valvular heart disease or contraindications to percutaneous ablation. In the initial 57 patients (group A), a novel approach to the MIL was performed, targeting the mitral isthmus using a conventional line design along the inferior portion of the mitral isthmus. All procedures were performed by 3 highly experienced operators, having performed >1000 left atrial (LA) interventions each. All patients provided written informed consent. The study was approved by the local ethics board and was performed in accordance with the Declaration of Helsinki.

Preprocedural Management
Transesophageal echocardiography was performed in all patients to rule out LA thrombus and to assess LA diameter prior to transseptal access. A dedicated LAA catheter (G2; Biosense Webster Inc.) was positioned in the LA to continuously monitor electric LAA activation during ablation of a mitral isthmus line. Before ablation. In patients on vitamin K antagonist, anticoagulation was stopped 3 days before ablation and replaced by intravenous heparin to maintain a partial thromboplastin time of 2 to 3 times of the normal value. Novel oral anticoagulants were stopped the day before the procedure.

Electrophysiology Study and Three-Dimensional Electroanatomic Mapping
The ablation procedure was performed under sedation using midazolam, sufentanil, and propofol. A 7-F multipolar electrode catheter was positioned in the CS via the right femoral vein or left subclavian vein. Double transseptal puncture using 8.5-F sheaths (SL1; St. Jude Medical Inc, St. Paul, MN) was performed using a modified Brockenbrough technique. After transseptal access, intravenous heparin was administered targeting an activated clotting time of >300 seconds. The transseptal sheaths were continuously flushed with heparinized saline to avoid thrombus formation. Selective pulmonary vein (PV) angiography identified the individual PV ostia.

Three-dimensional (3D) electroanatomic mapping of the LA (Carto; Biosense Webster Inc., Diamond Bar) was performed using a 3.5-mm irrigated tip catheter (ThermoCool Navi-Star; Biosense Webster Inc.). After 3D reconstruction of the LA, the ipsilateral PV ostia were tagged on the electroanatomic map according to angiographic and electrophysiologic criteria. If necessary, the CS was mapped and displayed on a separate map.

Ablation Strategy During First and Repeat Procedures
Our ablation strategy for AF has previously been described in detail.3,7 In brief, electric isolation or reisolation of all PVs was performed. Patients in continuous AF after wide-circumferential lesion ablation encircling the ipsilateral PVs underwent biphasic electric cardioversion to verify successful PVI in SR. Only in cases of unsuccessful electric cardioversion or reintubation of AF after electric cardioversion (PVI nonresponders), ablation targeted complex fractionated atrial

Figure 1. Fluoroscopic and angiographic visualization. Biplane angiographic visualization of the left atrial appendage (LAA) in right anterior oblique (RAO) 30°/caudal 15° and left anterior oblique (LAO) 45° projections (A and B). C, Fluoroscopic illustration of the position of the mapping catheter (Map) along the superior mitral isthmus at the base of the LAA in a RAO 30°/caudal 15° projection. A multipolar electrode catheter was positioned in the coronary sinus (CS). In C, a circular mapping catheter was positioned inside the LAA to continuously monitor electric LAA activation during ablation of a mitral isthmus line.
electrograms within the LA, right atrium, and CS. If AF converted to an AT, activation and entrainment mapping was performed, and linear lesion sets were deployed according to the underlying tachycardia mechanism. During ablation of complex fractionated atrial electrograms or deployment of linear lesion sets, a decapolar circular mapping catheter (Lasso; Biosense Webster) was positioned inside the LAA that continuously monitored electric LAA activation. Electrophysiological evidence of bidirectional block across all ablation lines was obtained after termination or cardioversion of AF/AT to SR. In patients with documented typical atrial flutter, bidirectional blockade of the cavotricuspid isthmus was performed. Durable PVI, as well as persistent block, across all linear lesions was ensured during a 30-minute waiting period.20

MIL Ablation

An MIL was deployed for the treatment of confirmed perimital reentry tachycardia. A decapolar circular mapping catheter (Lasso; Biosense Webster) was positioned inside the LAA, and a 7-F multipolar electrode catheter was placed within the CS with the proximal and distal electrodes spanning the mitral isthmus. CS angiography was not routinely performed to visualize the vein of Marshall. In both groups, irrigated radiofrequency energy was delivered to the endocardial surface with a maximum target temperature of 43°C, a maximum power of 40 Watts, and a flush rate of 25 mL/min. Endocardial ablation was considered a failure if only wide double potentials suggesting local conduction block were recorded along the endocardial linear lesion, but adjacent electrodes of the CS catheter exhibited early activation. In this case, epicardial ablation from within the CS was performed, limiting power delivery to 20 Watts and a flush rate of 17 mL/min. In addition, the catheter tip was directed toward the endocardial layer. Conduction via the mitral isthmus was continuously monitored during catheter ablation, and conduction block across the deployed lesion set was confirmed during sinus rhythm during a 30-minute waiting period.

Bidirectional conduction block was defined as widely spaced double potentials recorded along the MIL when pacing from either side of the line (e.g., cranial from the LAA or caudal from the distal CS). Pacing from the LAA cranial to the MIL resulted in a proximal-to-distal propagation sequence on the CS recording catheter (Figure 2). Differential pacing was used to discriminate conduction block from slow conduction across the MIL. As the site of pacing is gradually moved away from the MIL, the stimulus-to-electrogram interval on the opposite side of the ablation line decreased in the setting of conduction block and increased in the presence of slow conduction.15,20 If wide double potentials were recorded from the endo- and epicardium, but ablation failed to terminate perimital reentrant tachycardia, careful remapping of the entire line was performed. All electrograms that failed to demonstrate local conduction block were targeted for ablation until double potentials were recorded, including electrograms at the annular end of the line. If necessary, electric cardioversion was performed to complete the MIL during pacing from the LAA.

To enhance catheter contact and stability, a regular long sheath (SL1; St. Jude Medical) but not a steerable long sheath was used in the study.

1. The superolateral MIL (group A): First, biplane angionicraphic visualization of the LAA was performed in right

![Figure 2. Surface ECG leads I, II, and V1 and intracardiac electrograms (100 mm/s) during superior mitral isthmus line (MIL) ablation.](image-url)
Pacing is performed from a circular mapping catheter positioned within the left atrial appendage (PV). During energy delivery, conduction block is observed, resulting in widely spaced double potentials (red arrows) recorded on the ablation catheter (Abl). Furthermore, the propagation sequence on the coronary sinus (CS) recording catheter changes from distal (CS 1/2) to proximal (CS 7/8) to proximal to distal.
anterior oblique 30°/caudal 15° and left anterior oblique 40° projections (Figure 1). The diameter of the LAA orifice was measured in right anterior oblique 30°/caudal 15° projection. The posterior neck of the LAA was then tagged on the electroanatomic LA map (Figures 3 and 4). Ablation was performed by drawing a horizontal line immediately inferior to the posterior aspect of the LAA orifice, connecting the anterosuperior aspect of the wide circumferential lesion set encircling the ipsilateral left PVs with the posterior mitral annulus, where the atrioventricular electrogram exhibited a 1:2 ratio.

2. The inferolateral MIL (group B): Ablation was performed as previously described by deploying a horizontal line from the anteroinferior aspect of the wide circumferential lesion set encircling the ipsilateral left PVs to the mitral annulus15 (Figures 3 and 4).

For this study, operators kept strictly to the novel superolateral MIL design in group A and to the conventional inferolateral MIL design in group B. There was no crossover between groups. The length of the MIL was defined as the minimal distance between the orifice of the PVs and the posterior mitral annulus at the level of ablation and measured at the end of the procedure using the 3D electroanatomical mapping system.

Study End Points
The primary end point was bidirectional conduction block across the MIL as confirmed by mapping and pacing maneuvers.

Secondary end points included (1) the need for epicardial ablation from within the CS to achieve conduction block, (2) reconnection across the mitral isthmus during repeat procedures, and (3) complications related to ablation of the MIL, such as pericardial tamponade and PV stenosis. Other procedural complications (transient ischemic attack, stroke, pneumo- or hematothorax, or severe bleeding from the access sites) were also reported. Hematoma at the access site or pericardial effusion requiring only conservative management were considered minor complications.

Postprocedural Care and Follow-Up
After ablation, all patients underwent transthoracic echocardiography to rule out pericardial effusion. All patients were treated with proton-pump inhibitors for 6 weeks. Low molecular-weight heparin was administered in patients on vitamin K antagonists and an international normalized ratio <2.0 until a therapeutic international normalized ratio of 2 to 3 was achieved. Anticoagulation was continued for at least 3 months and thereafter based on the individual CHA2DS2-VASc score. Previously ineffective antiarrhythmic drugs were continued for 3 months. Twelve-lead ECG and Holter recordings were performed before hospital discharge to confirm stable sinus rhythm.

In patients presenting for a repeat ablation procedure because of arrhythmia recurrence, conduction block across previously deployed linear lesions was evaluated. When available, details from coronary angiography performed after MIL ablation were collected.

Statistical Analysis
Data were analyzed descriptively in the following way: Continuous data were summarized with mean and standard deviations or median, as well as 25th (Q1) and 75th percentiles (Q3). Differences in baseline characteristics between groups were analyzed with an F-test of no regression. Continuous variables were compared using Student’s t test or the Mann–Whitney U test. Categorical data were presented with frequencies and proportions. Categorical variables were compared using Fisher exact test. Differences in the length of the MIL were examined using Welch’s 2-sample t test. All P values were 2-sided. P<0.05 was considered significant. All calculations were performed with the statistical analysis software R (R Foundation for Statistical Computing, 2017, Vienna, Austria).

RESULTS
Baseline Patient Characteristics
Detailed patient characteristics of the 114 patients included in this analysis are summarized in Table 1. There was no difference between both groups with regard to baseline characteristics (P=0.21).

During the course of the study, ≈1000 patients underwent catheter ablation for persistent AF at our institution. Among 114 patients included in the analysis, AF organized into perimital reentrant tachycardia during the ablation procedure in 37 of 57 (65.0%) patients in group A and 39 of 57 (68.4%) patients in group B. Conversely, perimital reentrant tachycardia was the presenting rhythm at the outset of the ablation...
procedure in 20 of 57 (35%) patients in group A and 18 of 57 (31.6%) patients in group B. The number of prior AF ablation procedures was 1.2±0.8 in group A and 1.3±0.9 in group B.

MIL Ablation

Characteristics of the 2 linear lesion designs are depicted in Table 2. The mean number of mapping points was 67.2±8.5 for the complete LA map. Out of these, 21.1±4.9 mapping point were taken around the mitral annulus, with special focus on the mitral isthmus region. The mean number of mapping points within the CS was 18.9±3.2. The average length of the superior MIL was 28.9±6.9 mm (group A), while the length of the inferior MIL was 31.8±7.2 mm (group B; P=0.07). The mean LAA orifice diameter was 21.4±2.3 mm. Mitral isthmus block was achieved in 56 of 57 (98.2%) patients in group A and 50 of 57 (87.7%) patients in group B, with borderline significant higher success in patients undergoing catheter ablation of the superior MIL (P=0.06). The need for epicardial ablation from within the CS was significantly higher in group B with 41 of 57 (71.9%) patients versus group A with 4 of 57 (7.0%) patients (P<0.01).

Failure of Mitral Isthmus Blockade

Patients with unsuccessful MIL ablation (8/114) demonstrated a longer mitral isthmus (29.3±6.35 mm versus 40.8±7.29 mm; P=0.005) and a significant higher need for epicardial ablation from within the CS (P<0.01).

Persistence of Mitral Isthmus Blockade in Patients Undergoing Repeat Procedures

During a mean follow-up of 4.8±0.3 years, a repeat ablation procedure because of arrhythmia recurrence was performed in 16 of 57 (28.1%) patients in group A at a median of 297 days (Q1, 141; Q3, 568) after the index procedure and in 17 of 57 (29.8%) patients in group B at a median of 368 days (Q1, 112; Q3, 983) after the index procedure. An AT was the presenting rhythm in 5 of 16 (31.3%) patients in group A and in 6 of 17 (35.3%) patients in group B. The remaining patients presented with recurrent AF. Persistent mitral isthmus block was documented in 8 of 16 (50%) patients in group A and 4 of 17 (23.5%) patients in group B.

Table 1. Baseline Clinical Characteristics

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Group A (Superolateral MIL)</th>
<th>Group B (Inferolateral MIL)</th>
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<tbody>
<tr>
<td>Age at index ablation, y</td>
<td>61.9 (±11.0)</td>
<td>64.8 (±10.0)</td>
</tr>
<tr>
<td>Sex (female)</td>
<td>15 (26.3%)</td>
<td>19 (33.3%)</td>
</tr>
<tr>
<td>Hypertension</td>
<td>39 (68.4%)</td>
<td>32 (56.1%)</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>3 (5.3%)</td>
<td>7 (12.3%)</td>
</tr>
<tr>
<td>BMI</td>
<td>26.1 (±4.4)</td>
<td>27.1 (±4.4)</td>
</tr>
<tr>
<td>CAD</td>
<td>9 (15.8%)</td>
<td>6 (10.5%)</td>
</tr>
<tr>
<td>LVEF, %</td>
<td>58.3 (±5.0)</td>
<td>57.1 (±7.7)</td>
</tr>
<tr>
<td>SHD</td>
<td>3 (5.3%)</td>
<td>2 (3.5%)</td>
</tr>
<tr>
<td>DCM</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>HNCM</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Prior cardiac surgery*</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Prior stroke</td>
<td>4 (7.0%)</td>
<td>2 (3.5%)</td>
</tr>
<tr>
<td>CHA2DS2-VASc score</td>
<td>2 [1,2]</td>
<td>1 [1,3]</td>
</tr>
<tr>
<td>LA diameter, mm</td>
<td>45.7 (±6.5)</td>
<td>46.8 (±6.5)</td>
</tr>
</tbody>
</table>

| AAD | Beta blocker | 54 (94.7%) | 46 (80.7%) |
| Class I AAD | 16 (28.8%) | 19 (33.3%) |
| Class III AAD | 21 (36.8%) | 16 (28.1%) |
| Anticoagulation | Vitamin K antagonist | 57 (100%) | 54 (94.7%) |
| Direct oral anti-coagulant | 0 (0%) | 3 (5.3%) |

Values are means±standard deviations and frequencies (percentages) or medians with 25th, 75th percentiles. P value = 0.21. AAD indicates antiarrhythmic drugs; BMI, body mass index; CAD, coronary artery disease; DCM, dilated cardiomyopathy; HNCM, hypertrophic nonobstructive cardiomyopathy; LA, left atrium; LVEF, left ventricular ejection fraction; MIL, mitral isthmus line; and SHD, structural heart disease.

*Coronary artery bypass graft only.

Table 2. Mapping and Ablation Data

<table>
<thead>
<tr>
<th>Group A (Superolateral MIL)</th>
<th>Group B (Inferolateral MIL)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Index procedure</td>
<td>Length, mm</td>
<td>28.9±6.9</td>
</tr>
<tr>
<td></td>
<td>Angiographic LAA orifice diameter,* mm</td>
<td>21.4±2.3</td>
</tr>
<tr>
<td></td>
<td>Bidirectional block</td>
<td>56/57 (98.2%)</td>
</tr>
<tr>
<td></td>
<td>Epicardial ablation within coronary sinus</td>
<td>5/57 (7.0%)</td>
</tr>
<tr>
<td></td>
<td>Pericardial tamponade</td>
<td>3/57 (5.2%)</td>
</tr>
<tr>
<td></td>
<td>Major complications</td>
<td>4/57 (7.0%)</td>
</tr>
<tr>
<td></td>
<td>Total procedure time, min</td>
<td>160.1 (±46.2)</td>
</tr>
<tr>
<td></td>
<td>Total fluoroscopy time, min</td>
<td>19.7 (±8.5)</td>
</tr>
<tr>
<td></td>
<td>Total RF time, min</td>
<td>31.6 (±14.0)</td>
</tr>
<tr>
<td>Repeat procedure</td>
<td>Patients undergoing repeat procedure</td>
<td>16/57 (28.1%)</td>
</tr>
<tr>
<td></td>
<td>MIL: recovery of conduction</td>
<td>8/16 (50%)</td>
</tr>
<tr>
<td></td>
<td>Epicardial ablation within coronary sinus</td>
<td>1/8 (12.5%)</td>
</tr>
</tbody>
</table>

Values are means±standard deviations and frequencies (percentages). LAA indicates left atrial appendage; MIL, mitral isthmus line; and RF, radiofrequency ablation.

*Craniocaudal direction.
Successful mitral isthmus block was achieved in all patients during the repeat procedure who presented with recurrent mitral isthmus conduction. Epicardial ablation from within the CS was required in 1 of 8 (12.5%) patients in group A and 6 of 13 (46.2%) patients in group B. All patients requiring epicardial ablation during the redo procedure had undergone ablation within the CS during the index procedure.

Findings on Coronary Angiography After MIL Ablation

None of the patients presented with symptoms of myocardial ischemia immediately after the index procedure. However, 14 of 15 patients with known coronary artery disease before MIL ablation underwent coronary angiography during follow-up because of suspected progression of coronary artery disease. Coronary angiography performed after a median of 219 days (Q1, 73.0; Q3, 421.5) after the index procedure reported no new or worsening stenosis of the left circumflex artery. None of the patients underwent computed tomography coronary angiography.

Complications

Major complications were observed in 4 of 57 (7.0%) patients in group A. Pericardial tamponade occurred in 3 of 57 (5.2%) patients and was successfully managed with pericardiocentesis without long-term sequelae. One patient had an arterial pseudoaneurysm. In group B, 3 of 57 (5.2%) patients had major complications, including 1 arterial pseudoaneurysm, 1 hematothorax related to subclavian vascular access, and 1 groin hematoma requiring surgery. No pericardial tamponade was observed in group B. No PV stenosis was documented in either group. In summary, statistical analysis revealed no significant difference for major complications (P>0.99) and pericardial tamponade (P=0.24). Minor complications included 1 pericardial effusion in group A and 2 pericardial effusions in group B, which remained asymptomatic and required no intervention.

DISCUSSION

The present study investigated the use of a novel ablation line design targeting the superolateral mitral isthmus. Compared with conventional ablation that targets the inferolateral aspect of the mitral isthmus, the herein described novel approach demonstrated (1) a borderline significant higher success rate to achieve bidirectional mitral isthmus blockade (98.2% versus 87.7%; P=0.06), (2) a significant reduction in the need for epicardial ablation from within the CS (7.0% versus 71.9%; P<0.001), and (3) an associated higher risk of pericardial tamponade (5.2% versus 0%; P=0.24). Furthermore, (4) the need for epicardial ablation from within the CS and a greater length of the mitral isthmus are both associated with unsuccessful bidirectional blockade across the MIL. Finally (5), during a repeat procedure because of arrhythm-

Figure 4. Anatomic endocast and endocardial surface.

In concordance with Figure 3, white points mark the ipsilateral ostia of the left pulmonary veins (LSPV, left superior pulmonary vein; LIPV, left inferior pulmonary vein); yellow points indicate the posterior base of the left atrial appendage (LAA), and red points delineate the anatomic course of the different mitral isthmus line designs. Left, Endocast displayed in a left-lateral projection depicting the course of the superolateral mitral isthmus line (MIL; A) and conventional MIL (B). Right, Endocardial surface of the left atrium (viewed in mirror-image fashion to endocast). Note the thin pale colored area (arrow) and pits and troughs in the vicinity of the superolateral MIL (A).
Anatomic Characteristics of the Mitral Isthmus Region and Procedural Success Rates

The complex and unique anatomic characteristics of the mitral isthmus region require careful consideration during linear catheter ablation. Myocardial depth, length between mitral annulus and lateral PVs, the presence of adjacent epicardial vessels, such as the CS and left circumflex artery, as well as endocardial cavities, may challenge or preclude successful bidirectional blockade of the mitral isthmus using radiofrequency ablation.

Along its horizontal course, the thinnest myocardial portion adjacent to the mitral annulus measures ~1.5 mm and continues to increase toward the lateral PV antrum, reaching a mean of 3 to 4 mm. Myocardial tissue depth of 5.2±1.8 mm at the inferior aspect of the mitral isthmus tapers down to 3.6±0.8 mm toward the superior section along the posterior base of the LAA. Myocardial depth, length between mitral annulus and lateral PVs, the presence of adjacent epicardial vessels, such as the CS and left circumflex artery, as well as endocardial cavities, may challenge or preclude successful bidirectional blockade of the mitral isthmus using radiofrequency ablation.

Furthermore, muscular sleeves around the CS connect to atrial myocardium and may result in ineffective endocardial linear ablation. The prevalence of these sleeves decreases as the CS extends distally. The superior aspect of the mitral isthmus is free of myocardial tissue encircling the great cardiac vein and the distal CS. Deployment of a superolateral MIL targets the mitral isthmus at its thinnest portion where bridging of an endocardial linear lesion by muscular sleeves encircling the CS is unlikely. Using this novel ablation strategy, acute success of bidirectional mitral isthmus blockade was achieved in all but one of 57 patients (98.2%). This represents the highest success rate reported for mitral isthmus ablation, varying widely in previous studies from 32% to 92%.13-17

As the aforementioned anatomic considerations may suggest, compared with the conventional inferolateral approach, deployment of a superolateral MIL along the posterior LAA orifice significantly reduced the need for epicardial ablation from within the CS (71.9% versus 7.0%; P<0.01). Furthermore, the need for epicardial ablation from within the CS was an independent predictor of failure to achieve bidirectional mitral isthmus block irrespective of the lesion design used. Recovery of mitral isthmus conduction remains the primary concern after successful deployment of an MIL and, in a previous study, was observed in as many as 73% of patients undergoing a repeat procedure because of arrhythmia recurrence.11 In the present study, recovery of mitral isthmus conduction was observed in 50% and 76.5% of patients during a repeat procedure because of arrhythmia recurrence using the superolateral and inferolateral approach, respectively. The role of the CS as a major cause for recovery of mitral isthmus conduction is further emphasized by the fact that in the present study, all patients requiring epicardial ablation during the redo procedure had undergone ablation from within the CS during the index procedure. Importantly, there is no data from previous studies or the current study on recovery of mitral isthmus conduction in patients without recurrent atrial arrhythmia. Therefore, the true incidence of recovery of conduction across the mitral isthmus is unknown and likely higher than reported in the present study.

Furthermore, a wider mitral isthmus was associated with failure to achieve bidirectional conduction block. A recent study reported that a narrow mitral isthmus independently predicted successful bidirectional blockade using an inferolateral approach,14 while other studies failed to corroborate this correlation.16,17

Finally, the individual dimension of the LAA orifice should be considered before deployment of a MIL. In the majority of patients, the base of the LAA orifice is at the level of or superior to the left superior pulmonary vein ostium. However, the take-off of the LAA ostium may be inferior to the left superior pulmonary vein in 12% of patients.21 Therefore, angiographic visualization of the LAA is paramount because an elongated LAA configuration in the craniocaudal direction with a relatively inferior outlet toward the mitral isthmus may interfere with a superior MIL design. In this study, however, none of the patients in group A demonstrated LAA dimensions that interfered with deployment of a superior MIL.

Complications

Previous studies reported major complications in ≤5% of patients undergoing catheter ablation for AF.22 In the present study, the rate of pericardial tamponade was higher in group A than in group B (5.2% versus 0%; P=0.24), despite use of identical energy settings during ablation. Similar rates of pericardial tamponade have previously been reported for MIL ablation.12,15,17 The higher incidence of pericardial tamponade in group A may be attributed to the thinner myocardial layer encountered at the level of the superolateral mitral isthmus and a greater prevalence of small crevices toward the base of the LAA.18 Positioning the catheter tip in one of these crevices during radiofrequency energy delivery may potentially lead to audible or silent steam pop formation. Careful impedance monitoring, as well as judicious adjustment of power delivery, may reduce the rate of pericardial tamponade, while the use of contact force sensing during MIL ablation may limit excessive catheter tip-to-tissue pressure. These preventive strategies will require further investigation.

During the study, no left phrenic nerve palsy was observed. Because in the majority of patients the left
phrenic nerve courses anterior superior to the mitral isthmus on top of the LAA and then descends along the lateral side of the left ventricle, the risk of nerve damage during deployment of the described MIL designs is negligible. To prevent inadvertent damage in case of an atypical anatomic course of the left phrenic nerve, pace mapping along its course prior to MIL deployment or monitoring of phrenic nerve function by continuous high-output pacing from the LAA may be performed.

Clinical Implications

While the incremental value of linear ablation has been challenged in the context of persistent AF, linear ablation remains an important strategy for the intervention- al management of macroreentrant AEs. Multiple linear lesion designs have been proposed, all of which bear their specific challenges. The conventional approach to MIL ablation connecting the left inferior PV antrum with the mitral annulus is the shortest lesion design for the treatment of perimitral reentry, but ablation is technically demanding, and epicardial ablation from within the distal CS is necessary in the majority of cases. An anterior line, connecting the wide-circumferential lesion encircling the ipsilateral septal or lateral PVs to the MA, has emerged as an alternative strategy to terminate perimitral reentry tachycardia. However, longer anatom- ic distance and, in many cases, dependence on abnormal voltage (implying thinning of atrial septal tissue) may limit successful contiguous lesion deployment.

The superolateral MIL adds to the electrophysiologist's armamentarium a novel ablative strategy for the treat- ment of perimital reentrant tachycardia. Preferably, a tailored ablation strategy targeting perimital reentrant tachycardia should be used that is based on the individual patient's characteristics, taking into account the specific electroanatomic substrate and LA geometry, as well as catheter stability along the target ablation site.

Because the LAA has been identified as a possible site of AF initiation and empirical isolation of the LAA may improve long-term freedom from AF/AT in patients with persistent AF, durable conduction block across the MIL is often necessary to achieve sustained LAA isolation. The latter emphasizes the role of the superolat- eral MIL as a novel and potent tool for AF/AT ablation.

Limitations

Routine computed tomography/magnetic resonance imaging was not performed in the study patients; hence, no individual data on the LA myocardial thickness are available. The hemodynamic impact of a superolateral or conventional MIL are unknown because LA contractility was not routinely assessed. Because of the retrospective design of this study, no data are available on the duration of radiofrequency energy delivery to complete the MIL or the exact anatomic site of tachycardia termina- tion during ablation along the mitral isthmus. Contact force-sensing catheters, steerable sheaths, or ultrahigh-density mapping were not used in the study, and their procedural impact remains unknown. Furthermore, only patients with arrhythmia recurrence underwent invasive study to test for electric reconduction across the MIL, potentially underestimating the true incidence of recovered mitral isthmus conduction. Similarly, coronary angiography was not performed systematically, potentially underestimating the true incidence of coronary artery stenosis. However, those patients presenting with symp- toms suggestive of coronary artery stenosis underwent coronary angiography. Finally, because there is some variation between patients regarding the number of prior AF ablation procedures, the study design does not allow for conclusions on the impact of mitral isthmus ablation on the overall late outcome.

Conclusions

The superolateral MIL is associated with a high acute success rate to achieve bidirectional block using endo- cardiac ablation only, with minimal need for epicardial ablation from within the CS. Predictors for unsuccess- ful bidirectional mitral isthmus block were the need for epicardial ablation from within the CS and a longer MIL. Compared with conventional MIL ablation, the incidence of pericardial effusion may be higher when targeting the superolateral mitral isthmus.

AFFILIATIONS


DISCLOSURES

None.

FOOTNOTES

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REFERENCES

Maurer et al; Ablation of the Superolateral Mitral Isthmus Line


Catheter Ablation of the Superolateral Mitral Isthmus Line: A Novel Approach to Reduce the Need for Epicardial Ablation

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