Atrial Arrhythmias After Single-Ring Isolation of the Posterior Left Atrium and Pulmonary Veins for Atrial Fibrillation
Mechanisms and Management

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Background—Single-ring isolation of the posterior left atrium is feasible, but the incidence and mechanisms of postprocedural arrhythmias have not been described in detail.

Methods and Results—The first 100 consecutive patients (58.8±11.2 years old, 80 male) who underwent single-ring isolation for atrial fibrillation (66 intermittent, 18 persistent, 16 long-standing persistent) were followed up for 9.1±4.5 months. Recurrences were diagnosed by clinical symptoms and Holter monitoring. Patients with recurrences of sustained atrial arrhythmia >3 months after the procedure were offered a repeat procedure and were studied to determine the mechanisms of recurrence. Forty-six patients (46%) experienced sustained postprocedural atrial arrhythmias (35 had atrial fibrillation, and 34 had atrial flutter). Of these, 34 required a second procedure 7.0±3.1 months after their initial procedure. Reconnection of the posterior left atrium was seen in all patients with atrial fibrillation. Atrial flutter was most commonly due to mitral isthmus-dependent macroreentry (n=8, cycle length 368±116 ms) or macroreentry through 2 gaps in the ring of lesions (n=6, cycle length 328±115 ms). Posterior left atrium reisolation was achieved at the second procedure in all patients. Atrial flutter was successfully ablated and rendered noninducible in all patients. Six months after their last procedure, the Kaplan-Meier estimate of freedom from recurrence for all 100 patients was 81±5%.

Conclusions—Atrial fibrillation and atrial flutter recurrence is common after single-ring isolation. Reconnection of the posterior left atrium and macroreentry are the common mechanisms. Repeat ablation results in satisfactory short-term outcomes. (Circ Arrhythmia Electrophysiol. 2008;1:120-126.)

Key Words: atrium • fibrillation • catheter ablation • atrial flutter

Circumferentially wide antral pulmonary vein isolation, with or without additional linear lesions, has been adopted by many centers for treatment of atrial fibrillation (AF). The reported success rates for ablation procedures range from 48% to 88% for paroxysmal AF and 0% to 79% for chronic AF after a single procedure. Failure may be due to recurrence of AF and atrial tachycardia due to macroreentry or focal mechanisms. Left atrial reentrant tachycardia has been reported in 6% to 16% of patients with pulmonary vein isolation.7,8

Clinical Perspective see p 126

Recently, we showed the feasibility of electrically isolating the pulmonary veins and posterior left atrium (PLA) with a single continuous ring of radiofrequency lesions.9 Short-term clinical outcomes were similar to a historical control cohort of patients undergoing circumferential pulmonary vein isolation with a ring around each ipsilateral vein pair. We hypothesized that the new single-ring procedure may lead to different patterns of arrhythmia recurrence. The purpose of this study was to characterize arrhythmias occurring after the single-ring procedure and determine the longer term efficacy of catheter ablation for treatment of these procedures.

Methods

Patient Population
Wide, electrically isolating percutaneous left atrial catheter ablation was performed in 100 consecutive consenting patients with intermittent (66), persistent (18), or long-standing persistent (16) AF to electrically isolate their pulmonary veins and PLA. No patients had prior left atrial ablation.
A single ring of ablation passed up the anterolateral to the left inferior pulmonary vein before ascending the lateral left atrial anterior to the left inferior pulmonary vein to join the start of the line (Figure 1C). By placing the circular mapping catheter sequentially in each of the veins, it was possible, by comparison with a coronary sinus reference electrogram, to determine which vein was activated first. The activation sequence in the earliest vein indicated whether this activation was coming from the adjacent segment of the ring of lesions or the section of the posterior wall between the veins, where there was uncertainty. The mapping catheter was placed on the posterior wall, within the ring, and adjacent to the earliest vein to determine the order of activation. Where the posterior wall was activated first, point-by-point activation was used to identify the earliest breakthrough in the roof or inferior line. Successful ablation at the gap (earliest point of activation within the ring) isolated the entire region within the ring (pulmonary veins and posterior wall) if there was a single gap. When >1 gap was present, ablation of the gap caused delayed and altered activation within the ring. The mapping process was repeated until all the gaps were abolished. The PLA and pulmonary veins were considered isolated when 3 criteria were fulfilled: (1) electrical activity was dissociated or absent within the ring of ablation lesions during sinus rhythm, (2) pacing the PLA and pulmonary veins did not capture the rest of the atria, and (3) pacing from the coronary sinus catheter did not result in associated electrical activity in the PLA or pulmonary veins.

A line of ablation was placed in the mitral isthmus joining the single ring of ablation near the left inferior pulmonary vein to the mitral annulus in 53 patients. The end point of ablation was bidirectional conduction block across the line. This was demonstrated by pacing the coronary sinus catheter both septal to and lateral to the ablation line. Conduction block across the line was defined as a delay >100 ms in conduction time and evidence of reversal of activation sequence distal to the line of ablation. If to epicardial connection was suspected, ablation was also performed in the coronary sinus (25 W). A cavotricuspid isthmus line of ablation was also performed in 90 patients.

**Repeat Procedure**

Patients in sinus rhythm at the start of the procedure were systematically checked for electrical isolation of the pulmonary veins and the PLA as described earlier. Patients in AF at the start of the procedure were electrically cardioverted to restore sinus rhythm. The previously isolated region within the ring was mapped to identify where the earliest activation was entering the PLA or pulmonary veins as described above. These areas were ablated, and if ablation resulted in isolation of the PLA or changed the site of earliest activation to another part of the ring, the ablation sites were considered a gap. Further gaps were mapped and closed with additional ablation to reestablish electrical isolation of the PLA and the pulmonary veins. Patients underwent rapid atrial pacing to induce atrial flutter after completion of the ring of lesions. Any further atrial flutters induced were characterized and ablated.

Patients in atrial flutter at the start of the repeat procedure were studied by using activation mapping and entrainment to locate sites suitable for ablation. Entrainment was performed in both atria to determine whether the tachycardia was macroreentrant or focal and to define whether the atrial flutter was right or left sided origin. Electroanatomic activation mapping was then performed, guided by the entrainment mapping to confirm the mechanism of the arrhythmia.

If needed, mitral isthmus ablations were performed as described for the first procedure. The previous ring of lesions was checked for gaps that were ablated as described earlier after successful ablation and restoration of sinus rhythm.

**Postprocedural Care and Long-Term Follow-Up**

Patients were not routinely administered antiarrhythmic medications after pulmonary vein isolation. Patients with symptoms suggestive of interatrial septum between the septal puncture site in the foram en ovale and the septal margin of the right pulmonary veins (Figure 1B). It then passed below the right inferior pulmonary vein and back across the PLA to below the left inferior pulmonary vein before ascending up the lateral left atrium anterior to the left inferior pulmonary vein to join the start of the line (Figure 1C).

**Procedures**

Procedures were performed under midazolam and fentanyl sedation or general anesthesia. Two transseptal punctures were performed, and long sheaths were used to position catheters in the left atrium. A fixed curve braided sheath was used to position a circular decapolar mapping catheter in the left atrium (Preface Multipurpose and Lasso catheter, Biosense Webster, Diamond Bar, Calif). A deflectable sheath (Ultimum Agilis, St Jude Medical, St Paul, Minn) was used to direct an open irrigated tip 3.5-mm tip, deflectable ablation catheter (Thermocoool Navistar, Biosense Webster). Mapping and ablation were guided by 3D rendering of the left atrium created from a multislice computed tomographic image integrated with the electroanatomic mapping system to guide ablation catheter navigation (CARTO Merge, Biosense Webster). Ablation sites were displayed on the rendered atrial surface.

Radiofrequency ablation power was limited to 40 W for the septum, left free wall, and roof of the left atrium. Power was reduced to 30 W during ablation of the PLA between the left and right inferior pulmonary veins and was further reduced to 25 W when ablation was required on the venous side of the ridge separating the left-sided veins and the left atrial appendage. Temperature was limited to 50°C. Ablation was continued at each site until the local electrogram was abolished (reduced to <0.05 mV) or for 30 seconds. Ablation was applied at 2- to 5-mm intervals.

**First Ablation Procedure: Single-Ring PLA Isolation**

The initial ablation procedure has been described in detail elsewhere. In brief, a single ring of ablation passed up the anterolateral margin of the ridge separating the left-sided veins from the left atrial appendage (Figure 1A). At the top of this ridge, it passed along the superior margin of the left atrial appendage onto the left atrial roof (Figure 1B). The roof was traversed, and the line continued down the
recurrence were investigated by electrocardiography or Holter monitoring. A 3-month blanking period was applied to exclude early recurrences that spontaneously resolved. Repeat procedures were offered to patients experiencing a recurrence of atrial arrhythmia >3 months after their first procedure. Patients who remained free of symptomatic recurrences had 7-day Holter monitoring to look for previously undetected atrial tachyarrhythmias at 6 months to identify asymptomatic arrhythmias.

Analysis
Continuous variables are expressed as mean±SD. Kaplan-Meier analysis was used to determine the likelihood of atrial arrhythmia recurrence. The log-rank test and Cox regression analysis were used to determine whether it was significantly affected by any patient or procedural variables. *P*<0.05 was considered statistically significant.

The study was approved by the Sydney West Area Health Service Human Ethics Committee, and all participants provided written informed consent.

The authors had full access to the data and take responsibility for the integrity of the data. All authors have read and agree to the manuscript as written.

Results

 Patients
Between February 2006 and September 2007, 100 patients underwent single-ring pulmonary vein isolation and were followed up for 9.1±4.5 months. Their mean age was 58±11 years, and 80 were male. AF had been present for 7.4±7.1 years, and these patients had failed treatment with 2.4±1.2 antiarrhythmic medications. Twenty-three patients had concomitant structural heart disease. Mean left atrial size on 2D echocardiography in the parasternal long-axis view was 42±7 mm. The PLA and pulmonary veins were successfully isolated in 96 (96%) patients.

 Recurrence After First Procedure
Recurrence atrial arrhythmia that was present >3 months after the first procedure occurred in 46 (46%) patients. Thirty-five (35%) patients had recurrence of AF, and 34 (34%) patients had recurrence of regular atrial tachycardia suggesting atrial flutter or focal atrial tachycardia.

 Repeat Procedure
A repeat procedure was performed on 34 patients with arrhythmia recurrence 7.0±3.1 months after the initial procedure. The mean total procedure time was 251±63 minutes, and mean total ablation time was 1444±980 seconds.

 Electrophysiological Study Findings
At the start of the procedure, 21 (62%) patients were in sinus rhythm, 1 (3%) was in AF, and 12 (35%) patients were in organized atrial tachycardia. Mapping revealed that 30 (88%) of 34 patients had breaches in the single ring of lesions that led to resumption of electrical activity in the previously isolated PLA, and 22 patients had >1 gap (mean 2.8±1.6 gaps per patient).

 Atrial Fibrillation
In total, 15 (44%) of the 34 patients who underwent a repeat procedure had AF recurrence after their first procedure. They all had gaps in their previous ring of isolating lesions resulting in associated electrical activity in the PLA and pulmonary veins. The gaps in the ring lesions were most commonly seen in the roof and along the ridge between the left-sided veins and the ostium of the left atrial appendage (Figure 2). Conversely, none of the 4 patients who still had intact isolation of the PLA had recurrence of AF after their first procedure (see later). Ablation of gaps in the ring was undertaken in the 30 patients who had reconnection of the PLA. At the end of the procedure, there was successful isolation of the PLA and pulmonary veins in all these patients.

 Regular Atrial Tachyarrhythmias Observed at Repeat Procedure
Organized atrial tachycardia was present in 12 (35%) patients at the start of the procedure and was inducible with rapid atrial pacing or by catheter manipulation in another 6 (18%) patients during the procedure. All of these 18 patients had clinically documented organized atrial tachycardia after their first procedure. Mapping of the atrial tachycardias showed that 16 of them had organized left atrial tachycardias, while the other 2 had typical cavotricuspid isthmus flutter. Atrial flutter was not induced in 9 of 25 patients who had documented organized atrial tachycardia after their first procedure. These 9 patients had gaps in the ring of lesions resulting in reconnection of the PLA and pulmonary veins. These gaps were closed at the repeat procedure. Five patients had >1 form of organized left atrial tachycardia. Two patients had both mitral annular reentrant tachycardia and ring breach-dependent atrial flutter. Two other patients with ring breach atrial flutter and a patient with mitral annular flutter also had other forms of atrial flutter that were not sustained enough to be mapped. These atrial flutters had cycle lengths that were different from the flutters that were mapped in these patients, and their mechanisms were unclear.

 Mitral Annular Macoreentrant Atrial Flutter
Mitral annular atrial flutter was found in 8 (24%) patients (Figure 3) with cycle lengths of 368±116 ms. Among the 34 patients who had a repeat procedure, 11 had an electrically intact mitral isthmus line created at the first procedure, 10 patients had an incomplete mitral isthmus line, and 13 patients did not have any mitral isthmus ablation. Ablation within the coronary sinus was not performed in any patients.
at the first procedure. Reconnection across an electrically intact mitral isthmus line created at the first procedure was found in 5 of 11 patients, and all of these patients had mitral annular atrial flutter at the repeat procedure. None of 6 patients who still had an intact mitral isthmus line had mitral annular flutter. One of 10 patients who had an incomplete mitral isthmus line and 2 of 13 patients who did not have a mitral isthmus line ablated at the first procedure had mitral annular atrial flutter at the second procedure.

Gap-Related Macroreentrant Atrial Flutter

Left atrial flutter sustained by reentry through at least 2 gaps in the ring was observed in 6 (18%) patients (Figure 4) with cycle lengths of 328 ± 115 ms. A gap in the ring was present in either the septum (n = 3) or the roof (n = 3) in all patients, together with another gap elsewhere in the ring. Activation in these cases entered the ring through 1 gap and exited to the remainder of the left atrium through a second breach in the ring. Ablation of these gaps terminated gap-related macroreentrant atrial flutter in all 6 patients.

Macrotelearright Atrial Flutter

Typical right atrial flutter, which was anticlockwise around the tricuspid annulus and dependent on the cavotricuspid isthmus, was observed in 2 (6%) patients. Of the 34 patients who had a repeat procedure, cavotricuspid isthmus ablation was performed at the previous procedure in 30 (88%) patients and was unsuccessful in only 1 patient. This patient had right atrial flutter, whereas the other had reconnection across a previously ablated cavotricuspid isthmus.

Seven other patients had reconnection across their previously ablated cavotricuspid isthmus, but they did not have inducible right atrial flutter. Right atrial flutter could not be induced in any of the 21 patients who still had an electrically intact cavotricuspid line or in the 4 patients who did not have any cavotricuspid ablation at the previous procedure.

Irregular Conduction of AF Through a Ring Gap

A single patient had a different form of atrial tachycardia characterized by irregular activation of the atria. There were...
procedures. After a mean follow-up period of 5.6 months, 27 of 34 (79%) patients who underwent a redo procedure remained free of atrial arrhythmias. On the basis of follow-up since their last procedure, the Kaplan-Meier estimate of atrial arrhythmia-free survival at 6 months after the procedure was 81 ± 5%.

Discussion

The main finding of this study is that approximately half of the patients who underwent single-ring PLA isolation had recurrence of an atrial arrhythmia, but a repeat procedure was usually successful in reestablishing sinus rhythm. Single-ring isolation of all pulmonary veins was followed by recurrence of atrial flutter in a high proportion of patients. However, these flutters had one of a small number of mechanisms and could usually be identified and treated effectively. We found at these repeat procedures that the reconnection of the previously isolated PLA and pulmonary veins was seen in a large majority of patients and that ablating any gaps in the ring of lesions led to resimulation of these structures. Recurrent macroreentrant atrial flutter was associated with discontinuity in the ring or previous ablation lines in the mitral isthmus or cavitricuspid isthmus. By reclosing these gaps, atrial flutter was rendered nondiscernible, and short-term follow-up showed that recurrence after a second procedure was uncommon.

Recurrent AF After Left Atrial Ablation and the Role of PLA

In previous studies of catheter ablation for AF, recurrence of atrial arrhythmias after a single percutaneous catheter ablation procedure, mostly AF, occurred in 12% to 85% of cases and was more common in patients with persistent or permanent AF rather than intermittent AF.2–5 Electrical reconnection in these studies was usually observed in patients who had recurrence of AF after these procedures and was thought to be the mechanism in most patients.5,6,12,13 The rate of AF recurrence in our study (35%) was nearly the lower end of the range reported in previous studies, for a cohort with a third of patients who have persistent or long-standing persistent AF. Recurrence of the previously isolated PLA and pulmonary veins was seen in all patients with recurrent AF in the present series. Moreover, AF did not recur in any of the 4 patients whose pulmonary veins and PLA remained isolated. This finding suggested that reconnection of the PLA was an important factor in AF recurrence. The PLA has been implicated in animal studies in the maintenance of AF.14,15 Mapping studies in patients with chronic AF have since demonstrated rapid repetitive electrical activity in the PLA.16,17 The PLA has also been shown to be a common site for the initiation and maintenance of AF.18,19 Electrically isolating this part of the left atrium may thus prevent the initiation and perpetuation of AF.

Recurrent Atrial Flutter After Left Atrial Ablation

Left atrial flutter has been reported rarely after segmental pulmonary vein isolation. Gerstenfeld et al20 found that organized left atrial tachyarrhythmia recurred in 2.9% of patients after this procedure, whereas AF recurred in 20%. At repeat ablation, only 1 in 10 patients had macroreentrant atrial flutter.

The incidence of left atrial flutters with pulmonary vein antral isolation techniques was higher than that seen with segmental pulmonary vein isolation at 11% to 14%.11,21

Other Atrial Tachycardia Mechanisms in Patients With Intact Rings

Four patients were found to still have electrically isolated posterior left atria and pulmonary veins, despite clinical recurrence of atrial tachyarrhythmias. In these patients, AF was not observed during follow-up after their first procedure or during the repeat procedure. These patients only had macroreentrant or focal tachycardias. Two patients had mitral annular atrial flutter. One patient had long complex fractionated signals near the base of the left atrial appendage with centrifugal activation of the left atrium from this site to the rest of the atria. This pattern was thought to indicate localized reentry in the left atrial roof outside the ring of ablation lesions. The last patient had an apparently focal atrial tachycardia arising from the ridge between the left atrial appendage and the left superior pulmonary vein. Activation from this region spread centrifugally to the left atrium outside the ring of lesions. The mechanism of this tachycardia was not clear, and local reentry could not be excluded.
Recurrent macroreentrant atrial arrhythmias were associated with gaps in ablation lines.21,22 Despite this, the addition of linear ablations in the roof or left mitral isthmus to this procedure has been shown to reduce the recurrence of atrial arrhythmias overall.11,21,23

Wide antral left atrial ablation with anatomic end points aiming for substrate modification but without electrical isolation is also associated with postablation left atrial flutter that is persistent in 4% to 16%,7,8,24 In patients who underwent a repeat procedure, mitral isthmus-dependent left atrial flutter was the most common mechanism.8,25,26 Gaps in previous ablation lines were thought to be responsible for creating these reentry circuits.25,26

The rate of atrial flutter recurrence we observed in our study was high compared with these previous studies at 34%. We found that mitral isthmus atrial flutters were frequently seen, as found in previous studies. We also observed that most of the recurrences were in patients who had undergone mitral isthmus ablation in their last procedure but who had reconnection across the line of ablation. In comparison, only 2 of 13 patients who did not have previous mitral isthmus ablation had mitral anular atrial flutter. It is possible that slow conduction across a recovered gap in the line predisposes to sustained atrial flutter. Further study will be required to elucidate the role of mitral isthmus ablation in the context of single-ring isolation of the PLA.

A second common mechanism of atrial flutter in this series was reentry through 2 gaps in the single ring of lesions (Figure 4). Mechanistically, this form of atrial flutter requires at least 2 gaps in the ring to be sustained. Where the flutter is dependent on 2 gaps, ablation of one of these gaps rendered atrial flutter noninducible, but the PLA was not isolated unless both gaps were closed by reablation. These macroreentrant flutters are due to recovery of conduction across the ring of ablation lesions as these patients all had an electrically isolating ring of lesions at the end of their previous procedure. Gaps in the ring resulting in electrical reconnection were most commonly seen in the roof line and also along the ridge between the left atrial appendage and the left pulmonary veins. This is not unexpected as we have previously noted that these were the regions that were most difficult to isolate in the initial procedure.8

Conclusions

Recurrent of atrial arrhythmias after single-ring isolation of the PLA and pulmonary veins is usually associated with reconnection across the ring of ablation lesions, resulting in electrical activity in the PLA and pulmonary veins or reconnection across previous ablation lines in the mitral isthmus. Left atrial flutter after this procedure is common, often due to macroreentry involving discontinuity in linear lesions. These recurrent atrial tachyarrhythmias are amenable to repeat ablation, and the short-term outcomes are satisfactory.

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Disclosures

Drs Thomas and Ross are the principal investigators for a National Health and Medical Research Council project grant titled “Circumvenous ablation for treatment of atrial fibrillation.” Dr Thomas has also received honoraria from Johnson & Johnson. R. McCall is a part-time employee of Biosense Webster. The remaining authors report no conflicts.

References

Atrial fibrillation (AF) ablation techniques continue to evolve in the quest for improved efficacy and safety. Recently, procedures that isolate the posterior left atrium (PLA) and pulmonary veins have been proposed by several groups, as the PLA has been implicated in the initiation and maintenance of AF and these procedures may also reduce esophageal exposure to ablation. However, their efficacy and mechanisms of recurrence are unknown. We studied 100 patients with AF (including 34 with persistent or long-standing persistent AF) who underwent en bloc single-ring isolation of the PLA and pulmonary veins and were followed up for 9.1 ± 4.5 months. Although recurrent atrial tachyarrhythmias were relatively common (46%), particularly as organized atrial tachycardia (34%), a repeat procedure was usually successful and resulted in a 6-month arrhythmia-free rate of 81%. At the repeat procedure, recovery of conduction into the previously isolated PLA was observed in patients who had AF recurrence. Organized atrial tachycardia was due to a small number of mechanisms. Mitral annular-dependent flutter was commonest and was frequently associated with reconnection across a previously ablated mitral isthmus line. Flutter sustained by 2 gaps in the ring of lesions was next most common. Whether this procedure is superior to other techniques is uncertain. The role of additional linear ablations (especially mitral isthmus ablation, which potentially may be proarrhythmic) in this technique is also not clear. Both these issues are currently under study.


CLINICAL PERSPECTIVE
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