A Novel Criterion for Conduction Block after Catheter Ablation of
Right Atrial Tachycardia after Mitral Valve Surgery

Running title: Atrial tachycardias after mitral valve surgery

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Abstract:

Background - One operative approach to the mitral valve, the superior trans-septal (STS) incision, is proarrhythmic because of extensive atriotomies. The objective of this study is to describe complex atrial tachycardias (ATs) that occur after this approach and propose methods to verify lines of block as an endpoint for catheter ablation.

Methods and Results - Of 69 patients who had electrophysiological studies for AT after mitral valve surgery, 20 patients had prior STS incisions. Of these, 14 had complex ATs involving the lateral right atrium (RA). There were 9 dual loop, 4 single loop and 1 focal tachycardia. Lateral wall ablation was performed by creating a linear lesion from the lateral atriotomy to either the inferior vena cava, superior vena cava, or tricuspid annulus, or ablating focally in the lateral RA. After a single ablation procedure, conduction block in the lateral wall was verified in 10 of 14 patients using one of two distinct patterns of block. One pattern consisted of late activation in an anterolateral corridor of the RA, and a second pattern consisted of wide spaced double potentials. Recurrent conduction through the lateral wall lesions was associated with intra-procedural and late recurrences of ATs.

Conclusions - The optimal endpoint for ablating ATs after mitral valve surgery with the STS approach is to establish lines of block that can be recognized by characteristic patterns of activation in the lateral RA. A novel criterion for lateral conduction block after catheter ablation is identification of a late-activated corridor in the anterolateral RA.

Key words: ablation; atrial tachyarrhythmias; catheter ablation; mitral valve
Introduction

Patients with prior mitral valve surgery often have areas of atrial scar and conduction block, which are related to the myopathic sequelae of valve disease but also result from atriotomy incisions and atrial cannulation sites. Reentrant atrial tachycardias (ATs), both single and dual-loop circuits as well as focal tachycardias, have been shown to arise in this patient population.\textsuperscript{1-5} Frequently, the substrate for reentry is related to atrial incisions with the location of the circuit being dependent on the type of surgical access used.

The main operative approaches to the mitral valve are the right lateral atriotomy, incision through the inter-atrial groove, transseptal incisions, and the superior transseptal (STS) approach. The STS approach involves an extensive series of incisions that involve the lateral and superior right atrium (RA), the inter-atrial septum, and the left atrial roof. Consequently, this surgical approach has been found to carry an increased pre-disposition towards ATs after surgery.\textsuperscript{6}

The purpose of this study is to describe complex patterns of right atrial activation that occur in patients with ATs after the STS approach to mitral valve surgery and to describe methods to verify lines of block as an endpoint for ablation in treating these arrhythmias.

Methods

Patient population

A retrospective single-center observational study was undertaken of patients who had electrophysiological studies for ATs after mitral valve repair or replacement. All patients who underwent electrophysiology studies for clinically documented refractory AT between January 2006 and January 2012 were identified. Patients were selected for inclusion if electrocardiograms demonstrated consistent, repetitive P-wave patterns, thus excluding patients whose index arrhythmias were atrial fibrillation. Among patients who met this criterion,
electrophysiology studies were then reviewed to identify patients in whom at least one well-defined AT could be mapped. Other patients with multiple ATs or inducible/spontaneous atrial fibrillation that precluded mapping were excluded from further analysis. The study protocol was approved by the local Institutional Review Board.

**Mapping and ablation**

All anti-arrhythmic drugs were discontinued a minimum of five half-lives before the procedures, except for 9 procedures which were performed within 3 months of taking amiodarone and 1 procedure which was performed while a patient was on flecainide. The location and number of diagnostic catheters were at the operators’ discretion, but generally included a 7F decapolar catheter in the coronary sinus, a 6F quadripolar His bundle catheter, and a duodecapolar catheter arrayed counterclockwise in the RA to record from the lateral wall. The mapping catheters were 3.5 mm or 4 mm tip quadripolar ablation catheters (Thermocool NAV, Biosense Webster, Diamond Bar, CA; Safire Blu, St. Jude Medical, St. Paul, MN).

Electroanatomical maps were obtained of the spontaneous clinical or induced AT. The critical limbs of the tachycardia circuit were delineated by activation and entrainment mapping. Entrainment was performed by pacing 20 to 50 msec less than the tachycardia cycle length. Sites with concealed entrainment and a post-pacing interval within 30 msec of the AT cycle length were considered to lie within the tachycardia circuit. Left atrial endocardial mapping was performed when activation and entrainment mapping were inconsistent with a right atrial origin or supported an origin in the left atrium. Three dimensional geometry and activation mapping of the atria were constructed with either CARTO (Biosense Webster) or EnSite NavX (St. Jude Medical) electroanatomical mapping systems. A coronary sinus electrogram with a stable cycle length and 1:1 activation with the mapped chamber was chosen as a reference for local
activation. Activation times were assigned based on the onset of bipolar electrograms, which were obtained with filter setting of 30 and 400 Hz. Macro-reentry was defined as activation that could be recorded over the entire cycle length and fulfilled entrainment criteria from several segments. A focal tachycardia was defined as atrial activity originating from a single focus and spreading centrifugally.

Ablation strategy

In cases of macro-reentry, the basic strategy was to interrupt a critical isthmus needed to sustain the tachycardia. Linear lesions were created with sequential ablations to connect anatomical barriers that defined this critical isthmus. Focal tachycardias were targeted at sites of earliest activation. Power was adjusted between 10 and 50W and ablation was continued for 30 to 60s at each site unless a rise in impedance occurred. Ablation was acutely successful if the tachycardia terminated during ablation and was not inducible with programmed stimulation.

Data collection and review

Operative reports were obtained for patients who met inclusion criteria and were reviewed by two authors (ANK and SMM). Surgeries were classified according to the surgical approach: 1) left atriotomy, 2) dissection in the interatrial groove, 3) transseptal approach, or 4) the STS approach. Patients who underwent the STS approach are the focus of this study. Concomitant MAZE surgery was also noted, and these patients were not included in the main analysis because the goal of this study was to describe arrhythmias related to the atriotomy lines as opposed to gaps in the MAZE lesion sets.

Follow-up

Patients were followed and monitoring was performed at the discretion of the treating physician. For the purposes of this study, patients were contacted by telephone if the medical record did not
contain results of a follow-up encounter, which included electrocardiograms, Holter monitors, outpatient telemetry, or device interrogation reports.

Statistical analysis

Continuous variables are expressed as median and interquartile ranges [25%,75%]. Differences between groups were analyzed with the Mann-Whitney test for continuous variables and Fisher’s exact test or chi-square test for categorical variables (Medcalc 12.2.1.0, www.medcalc.org). All reported p-values were based on two sided tests and were compared with a significance level of 0.05.

Results

Patient population

A total of 69 patients (age 73 [61,79], 49 male) with prior mitral valve surgery who collectively had 86 electrophysiology studies between January 2006 and January 2012 were included in this study. Operative reports were available for review in 63 (91%) patients. Ten patients had reoperations and the reports for the first operation were available for 3 of these patients, yielding 66 operative reports that were reviewed. The operative approach was a left atriotomy or dissection in the interatrial groove in 36 patients (55%), transseptal approach in 3 patients (5%), the STS approach in 26 patients (39%), and an aortotomy in 1 patient. There were no significant differences between patients who had the STS and other approaches in terms of age at surgery, gender, re-operation, concomitant surgery, or time from surgery to ablation (Supplemental Table 1).

Twenty patients underwent the STS approach without concomitant MAZE procedure. Of this group, 4 patients (20%) had multiple ATs or unmappable tachycardias during the electrophysiological studies, which precluded definitive mapping. Among the remaining 16
patients who had the STS approach without MAZE, 2 (12%) had only CTI-dependent atrial flutter, and 14 (88%) had other complex but mapable ATs.

For comparison, 25 patients had left atriotomies (either posterior left atriotomies or dissection in the interatrial groove) without concomitant MAZE, and 11 (44%) presented with CTI-dependent flutter alone, 6 (24%) with other complex ATs, and 8 (32%) with multiple unmappable ATs or atrial fibrillation (p=0.006 for comparison with STS approach).

Baseline demographics of the 14 patients with STS surgery and mapable complex ATs are presented in Table 1.

Tachycardia properties during initial procedures:

In all 14 patients, mapping during sinus rhythm and/or AT revealed areas of scar in the lateral RA wall, corresponding to the previous surgical incision. Twenty ATs were induced during the first electrophysiology study in these patients, of which 15 tachycardias were fully mapped. In 8 patients, a characteristic pattern of activation was recorded with a multipolar catheter in the lateral wall during AT, consisting of progressively narrowing double potentials bridged by an area of fractionation (Figure 1). This was interpreted as descending and ascending wave fronts in the lateral wall separated by a line of block due to the atriotomy scar, with an area of fractionation forming a “pivot point” between these wave fronts. Concealed entrainment with short post-pacing intervals could be demonstrated from various locations in the lateral wall in 10 patients, confirming participation of the lateral wall in the AT circuit. In 7 of these cases, entrainment pacing was performed in both anterior and posterior locations in the lateral wall or from the bridging area of fractionation, and these each fulfilled criteria for participation in the tachycardia circuit (Figure 2).

Critical limbs of the tachycardias, which were identified by entrainment and
electroanatomical mapping, revealed 9 dual loop tachycardias, each of which included the lateral wall and CTI as critical limbs (Table 2). There were 4 single loop tachycardias involving the lateral wall and 1 focal tachycardia in the lateral tricuspid annulus. In one patient, there were 2 tachycardias that rotated in opposite directions but utilized the same limbs around the atriotomy scar. Adenosine was administered during 13 tachycardias. All were adenosine-insensitive except for the focal tachycardia in patient #11, which was adenosine-sensitive.

Approaches to ablation:

In cases of dual loop tachycardia, ablation was initially performed in the CTI in most patients (N=8), since the initial activation patterns and entrainment revealed participation of the CTI. In cases of dual loop tachycardias, ablation in the CTI led to change in activation pattern (N=7) with slowing of the tachycardia cycle length by 13 to 69 msec (median 25 msec).

Verification of line of block – pattern 1:

Conduction block in the lateral wall was verified in 10 of 14 patients during their first ablation procedure. In 4 patients, conduction block was verified by a marked delay of activation in the anterolateral segment of the RA (Pattern 1). This pattern is demonstrated and interpreted from a representative patient shown in Figures 3 and 4. After ablation was performed in the CTI there was a change in lateral wall activation but the tachycardia persisted. Ablation was then performed in the lateral wall between the lateral atriotomy and the IVC, during which the AT terminated and sinus rhythm resulted. Figure 3A demonstrates two wave fronts in the lateral
wall during sinus rhythm initially after termination of the AT, with a posterior descending wave front and an anterior wave front. The anterior wave front was fused in the mid lateral wall, consistent with conduction through the CTI. After further ablation in the CTI, activation of the anterior wave front changed to reflect conduction through a gap in the lateral wall (Figure 3B). Further ablation from the lateral wall to the IVC resulted in block along the lateral wall in addition to the CTI. Coincident with this development, the anterior wave front now activated in a descending direction and was markedly delayed (Figure 4). When both lines of block were achieved, the low anterolateral RA was activated late after the coronary sinus. Time from P-wave onset to low anterolateral wall ranged from 183 to 262 msec (median 198 msec), and conduction time from proximal CS to low anterolateral wall ranged from 88 to 202 msec (median 115 msec). Sinus activation thus proceeded sequentially from the posterior right atrium, over the roof activating the postero-septum in a descending manner, under the septal incision and activates the tricuspid annulus in a counterclockwise manner (Figure 4B). The two ablation lines essentially compartmentalize the anterolateral RA to produce a “dead end” corridor. In the case shown in Figures 3 and 4, AT remained inducible with a slower cycle length when the lateral wall demonstrated the breakthrough pattern seen in panel 3B. AT became non-inducible when the lateral wall showed complete block across both lines, as indicated in Figure 4. This pattern of a descending and delayed anterior wave front occurred in patients who had separate ablation lines created in the CTI and the lateral wall, either as linear lesions to the IVC or focally in the lateral wall. In 1 other case (patient #8), the pattern of activation at the end of the first procedure reflected a line of block in the lateral wall but not the CTI.
Verification of line of block – pattern 2:

In 5 patients, conduction block along the line was verified by widely spaced double potentials (two components with a clear isoelectric interval; Figure 5) recorded along the ablation line either during normal sinus rhythm or with pacing close to the line (Pattern 2). The median interval between double potentials was 138 msec (range 94 to 222 msec). This pattern was present in patients who had ablation from the incision to tricuspid annulus, from the incision to SVC, and focal ablation in the lateral wall.

Incomplete verification of line of block:

In 3 patients, line of block across the lateral ablation line could not be verified at the end of the first procedure, and in 1 of 8 patients who had ablation in the CTI, conduction block could not be verified in this line. In 1 other patient, verification of either line of block was not performed due to the fact that there was ablation of a focal tachycardia. In all cases, AT was not inducible at the end of the initial procedure.

Subsequent procedures:

There were recurrent arrhythmias in 7 of the 14 patients leading to repeat electrophysiology studies with a median interval of 14 months (range 1.3 to 49 months). Of the 3 patients who did not have line of block verified in the lateral wall after the first procedure, 2 presented for another procedure; the 1 patient without block in the CTI also presented for reablation of CTI-dependent flutter. Of the 10 patients who did have line of block verified in the lateral wall in the first procedure, 4 presented for a second ablation.

Recovery of conduction and ablation in repeat procedures:

Conduction recurred in the lateral wall alone (1 patient), the CTI alone (2 patients), or both the lateral wall and CTI (2 patients). In the example of patient #2 (Figure 6), there was recovery of
Conduction in both the lateral wall and CTI, as evident by the decrease of the conduction delay from the coronary sinus to lateral wall from 115 msec to 25 msec. Consistent with this, tachycardias with critical limbs in both the lateral wall and CTI were inducible until lines of block were re-established in both regions. In 1 patient, lines of block were still present in both the lateral wall and CTI during the repeat procedure. Consistent with this, the recurrent clinical AT involved re-entry in the posterior wall but not the anterior wall or the CTI. The status of the original ablation lines could not be evaluated in 1 patient due to multiple unmappable tachycardias and atrial fibrillation in the subsequent procedure.

Conduction block, in either pattern 1 or pattern 2, was confirmed in 11 out of 13 patients with well-defined macro-reentrant tachycardias after the last procedure. During a median follow-up of 37 months (IQR 18, 46 months), atrial tachyarrhythmias recurred in 4 patients (recurrence rate 29%). One patient who originally had focal AT (#11) developed recurrent AT. Other recurrences in patients with macroreentrant AT were paroxysmal atrial fibrillation, paroxysmal AT, and chronic AT, each in 1 patient.

Discussion

This study shows that one particular operative approach to the mitral valve, the STS incision, results in complex patterns of RA activation due to the extensive atriotomies that involve the lateral RA, superior RA, and interatrial septum. These patients are therefore predisposed to reentry involving the lateral wall atriotomy, which occurred more commonly in this series than CTI-dependent atrial flutter alone. These arrhythmias often took the form of dual loop tachycardias involving the CTI and the lateral atriotomy. A characteristic finding during ATs was a pattern of ascending and descending wave fronts that could be recorded from multipolar catheters that spanned the atriotomy in the lateral wall. With high density mapping, an area of
fractionation could be identified between these wave fronts, which represented a “pivot point” in
the lateral wall, often between the atriotomy and the IVC. Identification of the second lateral
wall circuit is crucial for successful ablation of these ATs, in that P-wave morphology and
intracardiac activation of the anterior RA may suggest typical CTI-dependent flutter. Rapid
scanning of the lateral wall with a multipolar catheter will identify a second wave front opposite
to peri-tricuspid activation, and entrainment can indicate if tissue posterior to the atriotomy
participates as a second loop. Perpetuation of the tachycardia during CTI ablation, often with
cycle length prolongation, should prompt investigation for the second lateral wall circuit. This
situation is analogous to ATs that occur after other right atriotomies, as with atrial septal defect
repair or myxoma resections. 2 7 4 8 But in the STS approach, the atriotomies are more extensive
and the additional ablation lines further compartmentalize the RA to a greater degree.

The STS approach is favored in some instances, particularly for re-operations in which
the anatomical landmarks can be obscured by fibrosis and dissection of the posteriorly located
left atrium is difficult. The STS atriotomies provide direct visualization of the mitral valve. But
this approach may be proarrhythmic in several ways, including creating a posterior line of block
in a circuit of typical flutter, providing a central obstacle during incisional atrial tachycardias,
creating an area of slow conduction between the atriotomy and other structures (tricuspid
annulus, IVC) and allowing for areas of conduction through incisions with significant slowing 6.
Shalij et al found that the majority of re-entrant tachycardias after mitral valve surgery are right-
sided and the circuit is most often typical CTI-dependent flutter. 4 In contrast, we found that
patients with AT or atrial flutter after the STS approach have more complex circuits. The vast
majority of ATs in this series proved to be macroreentrant, although focal tachycardias may also
occur after mitral valve surgery. 1 These foci typically arise adjacent to areas of scar, as was
seen in 1 patient in this series.

Ablation approaches to lateral wall reentry and verifying lines of block

Different ablation lines can be designed to interrupt the reentrant arrhythmias that occur after this type of surgery. In our series, ablation was initially performed in the CTI in many patients, because the presenting rhythm demonstrated characteristics of peri-tricuspid reentry. This approach requires a second ablation line, which can be created between the lateral atriotomy and the IVC. If complete, these two ablation lines effectively segment the RA and result in a distinctive pattern of activation in the lateral wall (pattern 1). In sinus rhythm, the pattern shows markedly delayed activation of the anterolateral RA. Wave front propagation is consistent with activation from the posterior RA (location of the sinus node) to the low interatrial septum, then counterclockwise around the tricuspid annulus. Thus, activation of the proximal coronary sinus precedes the lateral RA, and there is a descending wave front in the anterolateral wall. Stepwise ablation of the CTI and the lateral wall results in variations of this pattern, as shown in Figures 3 and 4.

An alternative ablation approach for dual or single loop reentry involving the lateral wall is to create a single line from the lateral atriotomy to the tricuspid annulus. It is not conclusive if this approach yields superior outcomes compared to other ablation lesions. This approach avoids segmentation of the RA into a late-activated anterolateral corridor. In addition, only 1 of 5 patients who had this approach developed a recurrence of lateral wall reentry. Line of block can be verified by demonstrating widely spaced double potentials, especially when pacing near the line. This criterion has been described for other ablation lines, such as the CTI, left atrial roof, or lateral mitral isthmus. However, we observed 1 patient with this pattern of block who later presented with isthmus-dependent flutter and was treated with ablation in the CTI.
(patient #14). This could be explained by breakdown in the lateral ablation line or a circuit involving tissue posterior to the atriotomy. In fact, variations of typical flutter have been described in which required components of the circuit exist in the posterior RA.\textsuperscript{12, 13 14}

Regardless of the ablation approach, verifying line of block across the ablation lesions is a critical endpoint for the procedure. This is supported by our finding that patients who achieved non-inducibility but without strict verification of line of block developed recurrent arrhythmias that required re-ablation (in 3 of 4 patients without verification of block in the lateral wall or CTI). Even when ablation established a line of block, some patients developed recurrent arrhythmias and were found to have resumption of conduction across these lines. Transient conduction block in the lateral wall could be detected during some procedures and intra-procedural resumption of conduction was associated with re-inducibility. When repeat ablation established lines of block, as verified through the techniques described here, patients had favorable long-term outcomes. These results are consistent with observations from other macroreentrant circuits, such as CTI-dependent atrial flutter, which show that a verified line of block is superior to non-inducibility as an endpoint for ablation.\textsuperscript{15} Other studies have shown that recurrences are common in patients who undergo ablation of AT related to lateral atriotomies.\textsuperscript{4, 16} This is probably related to the technical difficulty of achieving a durable line of block in the lateral wall, as evidenced by intra-procedural and late recovery of conduction across these lines.

Limitations

This study was a retrospective review of patients with the STS approach to mitral valve surgery, and not all patients in this series were prospectively evaluated for the patterns of block described here. Thus, in some patients the lines of block might not been detected even if they were
established. Nevertheless, if a line of block was not identified even with this retrospective review, we found that ATs were likely to recur.

The upper limb of these reentrant circuits was not defined in many cases. It is not known if the septum is also involved in addition to the lateral wall. However, it is not necessary to define the complete circuit of these arrhythmias, and ablation is effective if critical limbs can be identified in the lateral wall and line of block can be confirmed.

The main results of this study are based on findings in 14 patients, who were identified from a larger population of 69 patients who had mitral valve surgery and ATs. This selection reflects the fact that most patients had left atriotomies and others were excluded because of unmappable tachycardias or maze surgery. Thus, other complex arrhythmias can be expected in patients who have different lesion sets, and other techniques must be considered to verify lines of block in these variable situations.

Conclusions

Surgical exposure to the mitral valve through the STS approach creates a substrate for macroreentry in the lateral RA wall, in the form of single or dual loop tachycardias. The optimal endpoint for ablating these arrhythmias is to establish lines of block that can be recognized by characteristic patterns of activation in the lateral RA. The combination of ablation lines in the CTI and inferolateral RA effectively segment the anterolateral RA. Other lines can be verified by widely spaced double potentials. It is likely that similar but modified criteria will be useful in verifying lines of block for arrhythmias that occur after other surgeries that involve right atriotomies.
Conflict of Interest Disclosures: Dr. Christopher F. Liu reports a research grand from Biosense Webster (≥ $10,000), has had honoraria from St Jude Medical (< $10,000) and from Biotronik (< $10,000). Dr. Jim W. Cheung has participated in the speaker’s bureau for Medronic (< $10,000) and for St. Jude Medical (< $10,000). Dr. George Thomas has participated in the speakers bureau for Boehringer Ingelheim (< $10,000) and has received honoraria from St Jude Medical (< $10,000). Dr. Steven M. Markowitz has participated in the speaker’s bureau for Sanofi-Aventis ($10,000) and has received honoraria from St. Jude Medical (< $10,000) and Medtronic (< $10,000). All other authors have nothing to disclose.

References:


Table 1. Patient Characteristics

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AF indicates atrial fibrillation; AI, aortic insufficiency; ASD, atrial septal defect; AVN, atrioventricular node; bioAVR, bioprosthetic aortic valve replacement; CABG, coronary artery bypass grafting; CAD, coronary artery disease; CVA, cerebrovascular accident; HTN, hypertension; NICM, nonischemic cardiomyopathy; PPM, permanent pacemaker; PVC, premature ventricular contractions; RHD, rheumatic heart disease; VT, ventricular tachycardia
Table 2. Procedural and Ablation Characteristics

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* Denotes ablation performed during normal sinus rhythm; † denotes non-inducible for sustained AT
‡ Denotes multiple unmappable ATs and AF. Ado indicates adenosine; AF, atrial fibrillation; Proc, procedure; SVC, superior vena cava
Figure Legends:

Figure 1. Recordings from a multipolar catheter in the right atrium (RA) lateral wall during atrial tachycardia (Patient #1). Displayed are surface leads I, aVF, and V1, recordings from the coronary sinus (Cs(p) to CS(d)), and from the lateral wall (High lat RA to Low lat RA). Double potentials with progressive narrowing are recorded in the lateral wall, consistent with descending and ascending wave fronts. A fractionated electrogram bridges the double potentials and is interpreted as a “pivot point” between the two wave fronts. Note that the ventricular beat is paced because of high degree AV block during atrial tachycardia.

Figure 2. Entrainment anterior and posterior to the lateral atriotomy. Panel A shows entrainment from the mapping catheter, which was located posterior to the atriotomy (Patient #3). Panel B shows entrainment from poles 9-10 of the multipolar catheter, which was positioned anterior to the atriotomy (same patient). Panel C shows entrainment from the mapping catheter, which was located at the “pivot point” in the lateral wall in another patient (#7). In all cases, the post-pacing interval was within 30 msec of the tachycardia cycle length. A schematic of the entrainment sites is indicated in the insert. In addition to surface leads, coronary sinus electrograms, and the multipolar catheter in the lateral wall, the figure shows recordings from the His bundle catheter (His p) and ablation catheter (ABL).

Figure 3. Conduction block in the lateral wall after ablation in the cavo-tricuspid isthmus (CTI) and lateral wall (Patient #1). Panel A shows lateral wall activation in sinus rhythm after termination of AT with ablation in the lateral wall between the atriotomy and the inferior vena cava (IVC). The anterior wave front is fused in the lateral wall, which reflects activation through
the CTI. After ablation in the CTI (B), activation of the lateral wall changes, with earliest activity in mid lateral wall, reflecting propagation from the posterior to the anterior RA through a gap in the lateral wall. Note that block must have existed in the lateral wall in panel A, but conduction recovered subsequently in panel B. Panels C and D show schematic interpretations of the wave front propagation in panels above. Electrograms as described in previous figures.

**Figure 4.** Conduction block in both the lateral wall and cavo-tricuspid isthmus. In the same patient in figure 3, further ablation in the lateral wall between the atriotomy and the IVC results in a descending and marked delayed anterior wave front, and the lateral wall is activated after the proximal coronary sinus. Red dotted lines indicate activation time of the proximal CS. Panel B is a schematic interpretation of wave front propagation in sinus rhythm after conduction block has been achieved in both lines. It shows a wave front originating from the sinus node in the posterior RA but does not traverse scar to the anterolateral RA (1). The wave front activates the posterior septum in a descending direction (2), then ascends the anterior septum (3), finally activating the anterolateral RA in a descending direction (4). Electrograms as described in previous figures.

**Figure 5.** Panel A: Electroanatomical map of atrial tachycardia showing lateral wall reentry (patient #3). Blue tags indicate double potentials in the lateral wall, and a line of block corresponding to the atriotomy is shown by double black lines. Entrainment sites posterior and anterior to the line are indicated by beige tags. Entrainment responses from these sites are shown in Figures 2A and B. Red tags are ablation lesions from the atriotomy to the lateral tricuspid annulus. The white tag is a recording site along the ablation line, which shows widely placed
double potentials after ablation, demonstrated in Panel B (pattern 2). Widely spaced double potentials were recorded along the ablation line while pacing from poles 7-8 on the multipolar catheter which were adjacent to the line. Standard catheter positions were used with the mapping catheter on the line in the anterolateral tricuspid annulus. MAP indicates mapping catheter.

**Figure 6.** Recurrent conduction in the lateral wall line of block (Patient #2). (A) Line of block in the lateral wall and CTI (pattern 1) is present after the first procedure. (B) Recurrent conduction through the lateral line of block is seen during the second procedure after the clinical tachycardia recurs. (C) Tachycardia is induced with programmed stimulation. (D) Line of block in the lateral wall and CTI is restored with lateral wall ablation, and no further ATs are inducible. In this panel, most electrograms on the multipolar RA catheter record from posterior to the line of block, but the mapping catheter is anterior to the line in the low lateral RA, and activation is markedly delayed.
Figure 1
Figure 3

A

I
aVF
V1
CS (p)
CS (p)
High lat RA
Low lat RA

133ms

Posterior Wavefront

1 2 3

Anterior Wavefront

118 ms

B

I
aVF
V1
CS (p)
CS (p)
High lat RA
Low lat RA

1 2 3

118 ms

1 2 3

SVC
Ao
PA
lateral LA
RPVs
lateral RA
RF lesions

SVC
Ao
PA
lateral LA
RPVs
lateral RA
RF lesions

IVC
Figure 5

A

B

I
aVF
V1
HIS(p)
HIS(d)
Cs (p)
Cs (d)
High
Lat RA
Low
Lat RA
MAP(p)
MAP(d)

222 ms
Figure 6

A

aVF
V1
CS (p)
CS (d)
High lat RA
Low lat RA

Posterior Wavefront
Anterior Wavefront

B

ABL (p)
ABL (d)

Breakthrough in lateral wall

C

ABL (p)
ABL (d)

D

Late activation anterolateral wall
A Novel Criterion for Conduction Block after Catheter Ablation of Right Atrial Tachycardia after Mitral Valve Surgery
Arvindh N. Kanagasundram, Amiran Baduashvili, Christopher F. Liu, Jim W. Cheung, George Thomas, James E. Ip, Shane D. Young, Bruce B. Lerman and Steven M. Markowitz

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### SUPPLEMENTAL MATERIAL

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* The operative approaches could not be determined in 6 patients. 1 patient had STS followed by re-operative non-STs surgery and is counted in the non-STs category for this comparison.

† Coronary bypass surgery, other valve surgery, maze, atrial septal defect closure