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# Original Article

# Pattern and Timing of the Coronary Sinus Activation to Guide Rapid Diagnosis of Atrial Tachycardia After Atrial Fibrillation Ablation

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***Background***—Atrial tachycardias (AT) during or after ablation of atrial fibrillation frequently pose a diagnostic challenge. We hypothesized that both the patterns and the timing of coronary sinus (CS) activation could facilitate AT mapping.

***Methods and Results***—A total of 140 consecutive postpersistent atrial fibrillation ablation patients with sustained AT were investigated by conventional mapping. CS activation pattern was defined as chevron or reverse chevron when the activations recorded on both the proximal and the distal CS dipoles were latest or earliest, respectively. The local activation of mid-CS was timed with reference to $P_{peak}$–$P_{peak}$ (P–P) interval in lead V1. A ratio, mid-CS activation time to AT cycle length, was computed. Of 223 diagnosed ATs, 124 were macroreentrant (56%) and 99 were centrifugal (44%). When CS activation was chevron/reverse chevron (n=44; 20%), macroreentries were mostly roof dependent. With reference to P–P interval, mid-CS activation timing showed specific consistency for peritricuspid and perimitral AT. Proximal to distal CS activation pattern and mid-CS activation at 50% to 70% of the P–P interval (n=30; 13%) diagnosed peritricuspid AT with 81% sensitivity and 89% specificity. Distal to proximal CS activation and mid-CS activation at 10% to 40% of the P–P interval (n=44; 20%) diagnosed perimitral AT with 88% sensitivity and 75% specificity.

***Conclusions***—The analysis of the patterns and timing of CS activation provides a rapid stratification of most likely macroreentrant ATs and points toward the likely origin of centrifugal ATs. It can be included in a stepwise diagnostic approach to rapidly select the most critical mapping maneuvers. (***Circ Arrhythm Electrophysiol***. 2013;6:481-490.)

**Key Words:** ablation ∎ atrial fibrillation ∎ atrial flutter ∎ atrial tachycardia ∎ coronary sinus ∎ electrophysiology mapping ∎ mapping

Catheter ablation of persistent atrial fibrillation (AF) often requires adjunctive substrate modification strategies beyond pulmonary vein isolation to achieve a higher success rate.[1,2] The expansion of ablation approaches that include a greater amount of left atrial (LA) ablation is associated with a high incidence of atrial tachycardias (ATs).[3–6] Mapping of these postablation ATs is often challenging and time-consuming because multiple foci may coexist and extensive atrial substrate has been targeted. It is, therefore, critical for the operator to have a preconceived suspicion of possible mechanism and AT location to avoid more exhaustive, and sometimes confusing, mapping and optimally rationalize the entrainment maneuvers. In this regard, and as a standard component of the electrophysiological evaluation, the analysis of the multipolar coronary sinus (CS) recordings provides a unique opportunity to rapidly guide the operator toward the most likely diagnosis by disclosing the pattern of activation of the inferior LA. We, therefore, aimed to better characterize the patterns of activation that may be encountered during AT to get as much information as possible from the CS recordings. We also hypothesized that the timing of CS activation during the AT cycle may help in the differential AT diagnosis.

## Clinical Perspective on p 490

The purpose of the study is to derive from the analysis of the CS recording a pragmatic strategy to select the most critical and limited number of activation and entrainment mapping maneuvers.

## Methods

### Study Population

All consecutive patients who underwent mapping and ablation of sustained AT arising during or after ablation of symptomatic drug-refractory persistent AF at our institute from January 2009 to May 2011 were enrolled in the study.
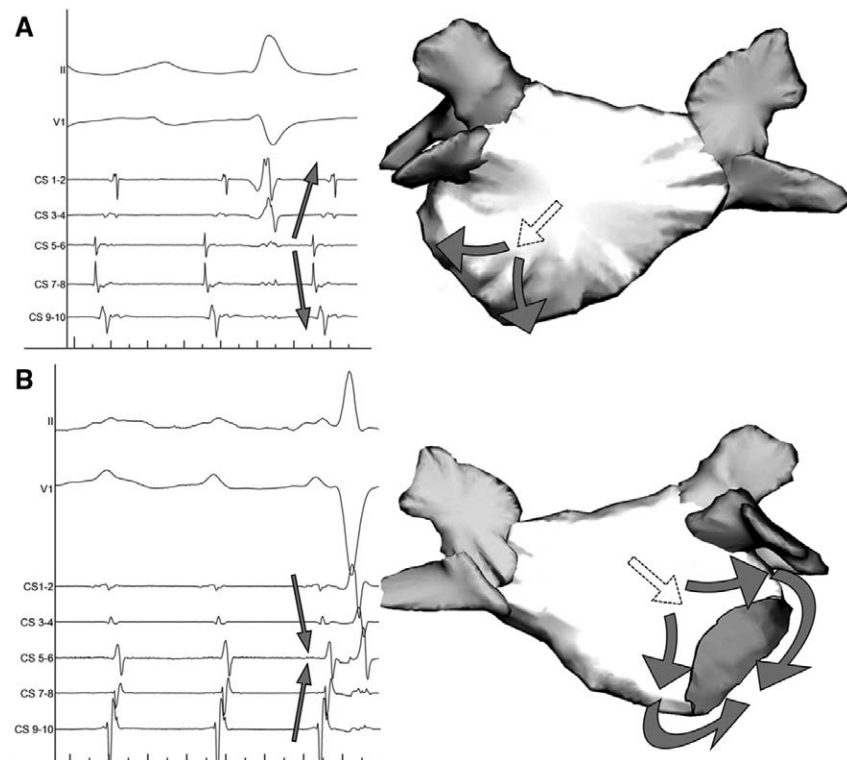
**Figure 1.** Chevron-like coronary sinus (CS) activation patterns. **A**, The chevron pattern results from the centrifugal activation of the CS from its mid portion (solid arrows) from a descending posterior wall activation (dashed arrow). **B**, The reverse chevron results from the fusion of 2 activation wavefronts (solid arrows) from a descending anterior wall activation (dashed arrow).

## Electrophysiological Study

All patients provided written informed consent. All antiarrhythmic drugs except amiodarone were stopped ≥5 half-lives before ablation. Surface ECGs and bipolar intracardiac electrograms (EGM) were monitored continuously and stored on a computer-based digital amplifier/recorder system (Labsystem Pro, Bard Electrophysiology, Lowell, MA). Signals were sampled at 1 kHz and filtered at 0.1 to 50 Hz for surface ECGs and 30 to 250 Hz for intracardiac signals, displayed at an amplitude of 0.1 mV/cm.

The following catheters were introduced through the right femoral vein: (1) a steerable decapolar catheter was positioned within the CS; (2) a 10-pole circumferential catheter (Lasso, Biosense-Webster, Diamond Bar, CA) was used for pulmonary vein mapping; and (3) a 3.5-mm externally irrigated-tip ablation catheter (Biosense-Webster, Diamond Bar, CA). The Lasso or the ablation catheter was stabilized with a long sheath (SLO, St. Jude Medical, St. Paul, MN) perfused continuously with heparinized solution. A single bolus of 50 IU/kg heparin was administered immediately after transseptal puncture. The activated clotting time was maintained thereafter within a range of 250 to 300 seconds.

## Ablation Sequence for Persistent AF

The index procedure for persistent AF was performed using a stepwise ablation approach with a procedural end point of AF termination. If AF converted into AT, ablation was performed until the restoration of sinus rhythm. Details of this particular ablation approach have been published previously.[1] In brief, as the first step, circumferential pulmonary vein isolation was performed. The second step, EGM-guided LA ablation, targeted sites displaying complex fractionated EGMs and locally short AF cycle length (CL). When ablation of the inferior LA did not result in organization of the CS, additional ablation within the CS was performed. Linear LA ablation, the third step, targeted the LA roof followed by the mitral isthmus (MI). In the presence of shorter AF CL in the right atrium, EGM-guided ablation was performed in that chamber. Cavotricuspid isthmus (CTI) ablation was performed in most patients.

## Characterization of the Patterns and Timing of CS Activation

The CS activation patterns were determined from the recordings of a steerable decapolar catheter (Xtrem, Alcis, Besancon, France), 2-5-2-mm electrode spacing. To reflect the left rather than right septal atrial activation, proximal bipoles were positioned 1 to 2 cm within the CS ostium, the location of which was estimated from the plane of the atrial septum in the left anterior oblique view. CS recordings were analyzed with high gain settings (0.1 mV/cm).

The CS activation pattern was categorized by 2 parallel criteria:

- The first criterion was based on the CS activation sequence. Four patterns were defined. The activation pattern was defined as proximal to distal when proximal and lateral CS bipoles were, respectively, the earliest and the latest. With reversal of activation, the CS activation pattern was defined as distal to proximal. The recording of the earliest activation on the mid-CS bipoles and the latest on both the proximal and the distal bipoles was defined as a chevron pattern (C pattern; Figure 1A). Inversely, the recording of the earliest CS activations on both the proximal and the distal bipoles and the latest on the mid-CS was defined as a reverse chevron pattern (D pattern; Figure 1B).
- The second criterion was based on the EGMs recorded along the CS. A uniform CS activation was defined as the recording of single potentials on each CS bipoles with sequential activation throughout the CS. A nonuniform CS activation was defined as the recording of double potentials on ≥1 contiguous CS bipoles. Two patterns were characterized: disparate LA-CS activation and stepped activation.

### Disparate LA-CS Activation

Because ablation often targets the endo- and epicardial aspects of the inferior LA/CS region, partial LA-CS disconnection may occur. As a consequence, split potentials may be observed with a disparate activation sequence of the 2 components along the CS because of a distinct activation of the local CS musculature and the contiguous LA. Details on the mechanisms and patterns of CS activation related to LA-CS disconnection during AT post AF ablation have been published previously.[7]

### Stepped CS Activation

Double potentials recorded on CS bipoles may alternatively both represent the LA endocardial activation and result from sensing on both sides of a line of conduction block or delay. In such cases, the number of CS bipoles with split potentials is confined to the bipoles that straddle the line of block. The staggered activation of the 2 LA segments overlying the split CS bipoles results in a stepped CS activation pattern.

In cases of nonuniform CS recordings, the first criterion (ie, the activation sequence) was categorized according to the actual endocardial LA activation for disparate LA-CS activation and, according to the activation of the proximal CS bipoles for stepped activation.

The timing of CS activation was referenced to the tachycardia P waves recorded on the surface ECG lead V1. Surface P waves were analyzed during higher (>2:1) grades of atrioventricular block. Recordings of 2:1 block were used when the P waves that preceded the QRS complexes were free of T waves. For single component P waves, the peak of the positive (or negative) deflection was used as reference ($P_{peak}$). For biphasic or multicomponent P waves, $P_{peak}$ was defined as the middle of the P wave deflection. The timing of CS activation was defined as the delay from $P_{peak}$ to the earliest activation recorded on bipoles CS-6 (mid-CS activation). A ratio was calculated by computing the $P_{peak}$ to mid-CS activation delay divided by the AT CL.

## Classification of AT

ATs were classified as macroreentry or centrifugal AT, the latter including focal AT and localized reentry.[8] Macroreentry was defined as reentry around a large central obstacle. A postpacing interval exceeding the AT CL by no more than 30 ms on 2 opposite segments of the central obstacle was required for diagnosis. Centrifugal AT was defined as atrial activity originating from a single focus and spreading out centrifugally. If activity accounting for >75% of the AT CL was present in an area with a diameter ≤3 cm, localized reentry was considered; and if not, a focal AT was considered.

## Mapping of Postablation AT

All ATs were conventionally mapped using a deductive strategy detailed previously.[8] Briefly, a combination of activation and entrainment mapping
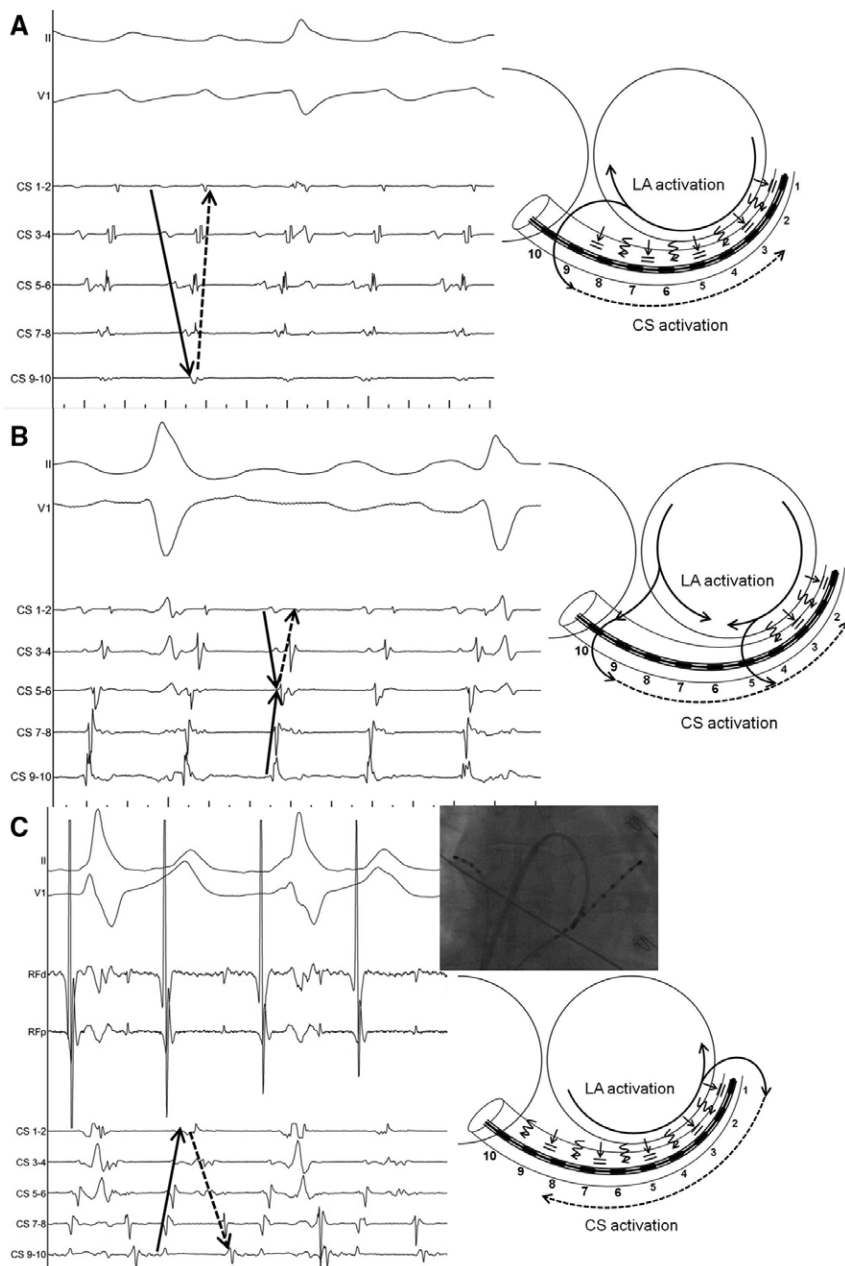


**Figure 2.** Disparate LA-CS activation patterns. **A**, Proximal to distal left atrial (LA) activation. Double potentials are recorded along the whole coronary sinus (CS). The early component, consisting of low-amplitude and broad potentials, represents the far-field LA endocardial activity (solid arrow). The second component, consisting of sharper potentials, represents the activation of the CS musculature and propagates in the opposite direction (dashed arrow). **Right**, The activation of the local CS musculature occurs when the endocardially propagating wavefront crosses over to the proximal CS epicardium (mid- and distal LA-CS disconnection). **B**, Reverse chevron LA activation. Double potentials are observed on the 2 distal CS bipoles; the broader potentials representing the far-field LA are activated earlier from distal to proximal (solid arrow on the distal CS), whereas CS musculature proceeds from proximal to distal (dashed arrow). **Right**, The distal LA-CS disconnection (up to CS bipoles CS 5–6) leads to the delayed distal local CS activation. **C**, Distal to proximal LA activation. The sequence of activation of the far-field LA is opposite to that shown in **A** (solid arrow). Endocardial mapping confirms that the local LA potential (RFd) facing CS 7 to 8 corresponds temporally to the first potential recorded on CS 7 to 8. **Right**, The local CS musculature is activated through intact distal LA-CS connections.
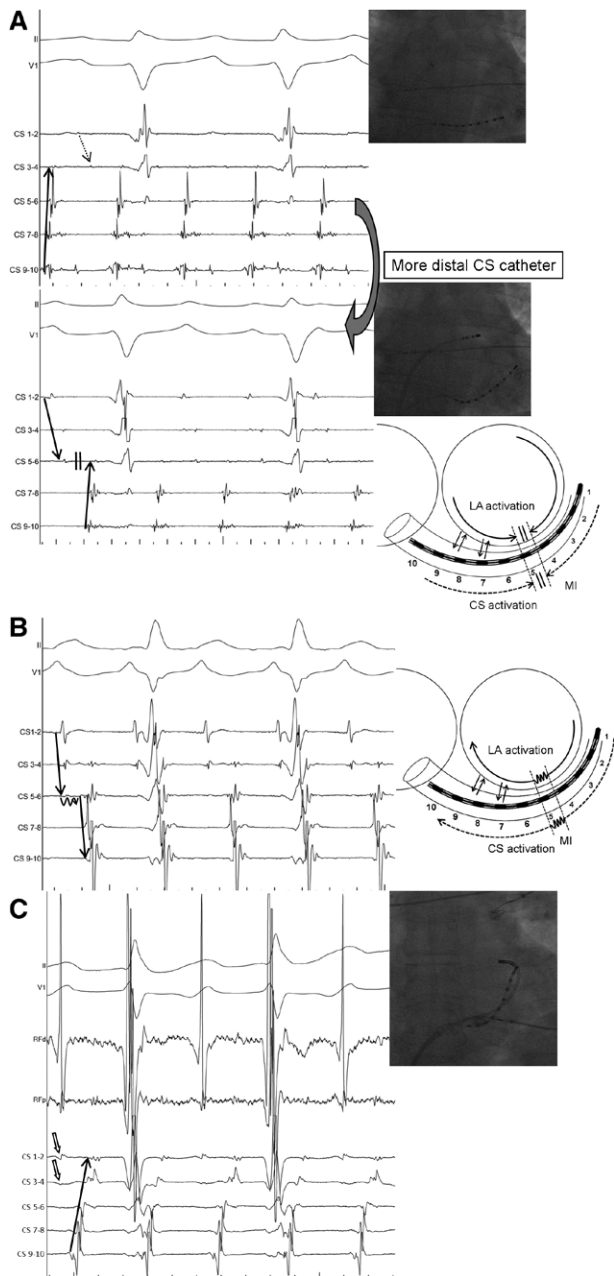
**Figure 3.** Patterns of stepped coronary sinus (CS) activation. **A**, Pattern 1: double potentials are barely discernable with a staggered activation of the distal 2 CS bipoles (dashed arrows). The activation on the proximal CS proceeds from proximal to distal (solid arrows). **Bottom**, A more distal positioning of the CS catheter allows to identify a distinct opposite activation pattern on the distal CS portion (ie, from distal to proximal). **Right**, This pattern results from 2 opposite inferior left atrial (LA) wavefronts activating both sides of a blocked MI line at different timings. **B**, Pattern 2: the 2 staggered activation pattern recorded on the proximal and distal portion of the CS are both parallel and proceeds from distal to proximal (solid arrows). **Right**, The delay recorded on CS 5 to 6 results from the slowed conduction through the underlying MI line. **C**, Pattern 3: the stepped activation consists of double potentials whose far-field components are recorded simultaneously with no discernable activation pattern. **Right**, These potentials corresponds temporally to the LA appendage activation (RFd) recorded distally on the anterolateral CS.

was then used to determine the mechanism and location of AT. As a first step, the possibility of a macroreentry was investigated. Atrial activation was mapped by systematically comparing the mapping catheter signals with a reference channel from the decapolar CS catheter. In the presence of a consistent activation sequence of the CS, a perimitral circuit was suspected or ruled out on the basis of the activation sequence of the anterior mitral annulus. In the absence of sequential circumferential activation of the mitral annulus, a roof-dependent reentry was mapped by looking for a cranial or caudal activation of the anterior and posterior LA walls. In the presence of similar or opposite directions of activation on both walls, roof-dependent reentry was ruled out or ruled in, respectively. Entrainment mapping was performed in 2 opposite segments as guided by the activation mapping. In the presence of a postpacing interval exceeding the AT CL by >30 ms in any segment, LA macroreentry was ruled out. A centrifugal AT was then mapped, initially in the LA and then in the right atrium. Repeated pacing maneuvers with analysis of the postpacing interval were also used to progressively approach the site of origin.

## Statistical Analysis

Continuous variables are given as arithmetic mean±SD and categorical variables as percentages. Analysis was performed using the software STATA, version 8 (Stat Corp, College Station, TX).

## Results

A total of 239 sustained ATs were analyzed in 140 consecutive patients who underwent 163 procedures. The mean age was 59±10 years and 81% were men. Patients had their first episode of AF a median of 84 months before ablation (limits, 5–276) and had persistent AF for a median of 10 months (limits, 0.5–132 months). They had failed treatment with 2.1±0.9 antiarrhythmic drugs, including amiodarone in 46%. The mean LA diameter was 46±7 mm in the parasternal window. Forty-three patients (31%) had an underlying structural heart disease. Mean left ventricular ejection fraction was 58±10%. AT occurred either during the index ablation procedure (29%) or late after AF ablation (71%).

The mechanism of 223 AT (93%) was elucidated, with sites of centrifugal AT confirmed by successful ablation. AT mechanisms could not be diagnosed in 16 cases: 8 AT (3%) were terminated during entrainment maneuvers and 8 (3%) could not be identified because of widespread alterations in EGMs.

### Mechanism of AT After Persistent AF Ablation

The mechanism of AT was macroreentry in 56% of cases and centrifugal in 44%.

Of the 124 macroreentrant AT, 66 were perimitral reentry (53%; 3 of which were figure-of-8 with a roof-dependent loop), 30 roof-dependent reentry (24%), and 26 CTI-dependent reentry (21%). Two additional atypical macroreentries were diagnosed: 1 right-sided reentry around the superior vena cava and 1 non-roof–dependent reentry around the LA appendage.

Of the 99 centrifugal AT, 79 were localized reentry (80%) and 20 were focal AT (20%). The origin of centrifugal AT was located in the LA and CS for the vast majority of cases (n=96; 97%) with only 3 centrifugal ATs originating from the right atrium (2 from the lateral wall and 1 from the superior vena cava).

### Prevalence of Different CS Activation Patterns During AT

The CS activation sequence in the 239 ATs was proximal to distal in about half of the cases (49%). In the remaining half,
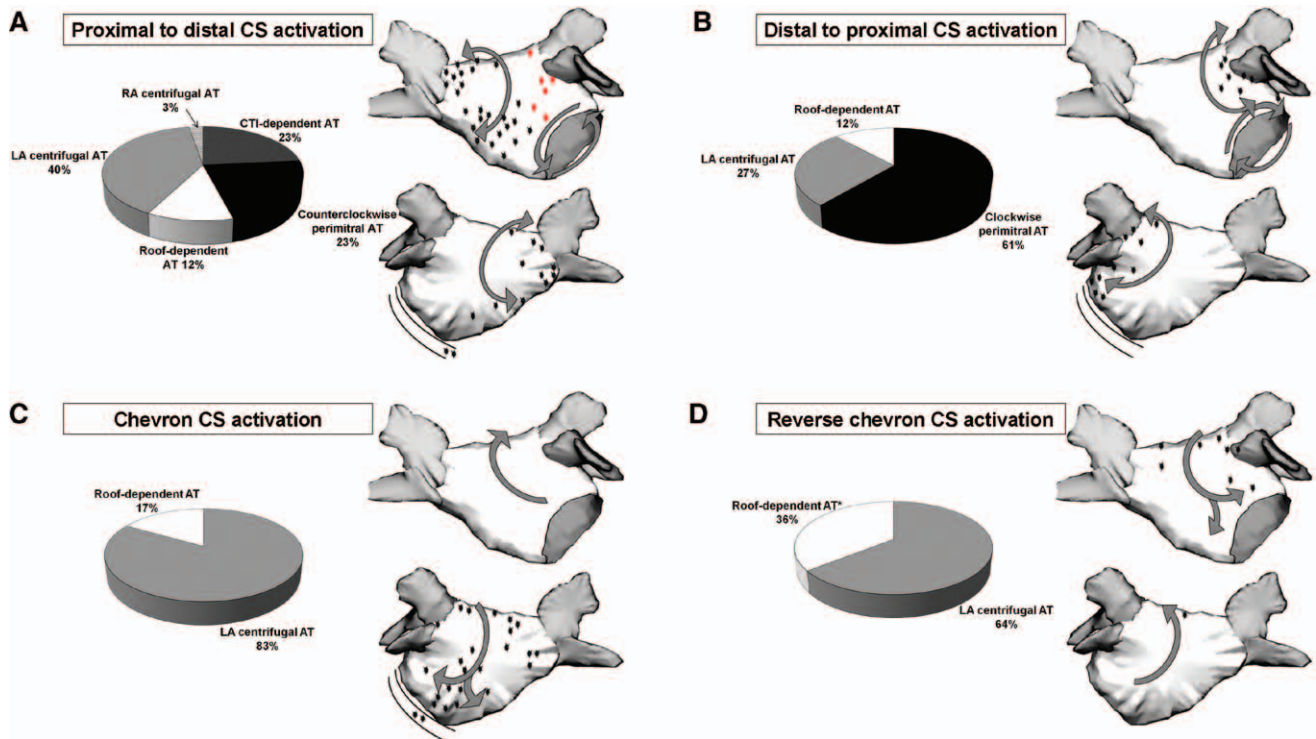
**Figure 4.** Diagnostic stratification based on the categorization of the coronary sinus (CS) activation. Proximal to distal (**A**), distal to proximal (**B**), chevron (**C**), and reverse chevron (**D**) CS activation. **Left**, Pie chart illustrating the prevalence of each atrial tachycardias (AT) mechanism. **Right**, Distribution of centrifugal AT sources and schematic activation of the left atrial (LA) macroreentries (solid arrows). In proximal to distal CS activation, centrifugal sources originating from the lateral side of the anterior LA wall were associated with MI block (labeled in red). *Including 1 atypical macroreentry around the LA appendage. CTI indicates cavotricuspid isthmus; and RA, right atrial.

the CS activation was distal to proximal in 31% of AT, chevron (C pattern) in 13%, and reverse chevron (D pattern) in 6%.

Although in most patients the CS activation pattern was uniform, a nonuniform activation was recorded in 25% of ATs (n=60). Nonuniform activation patterns were related to disparate LA-CS activations in 33 ATs (54%), stepped activation in 23 (39%), and both disparate LA-CS and stepped activation in 4 (7%).

In disparate LA-CS activation, the activation sequence of the clinically relevant far-field inferior LA myocardium was from distal to proximal in 70% of cases (n=26; Figure 2A), chevron/reverse chevron in 16% (n=6; Figure 2B), and from proximal to distal in 14% (n=5; Figure 2C).

In stepped CS activation, despite the recording of split potentials on the lateral CS, the MI line was blocked only in about half of the cases (59%; n=16). Three patterns of activation were observed (Figure 3).

Pattern 1 (n=11; 41%): a distinct pattern of the staggered activation recorded on the distal portion of the CS could be identified; the activation proceeded from distal to proximal, opposite to the activation recorded on the proximal portion of the CS (ie, from proximal to distal). In doubtful cases, a more distal positioning of CS catheter could allow a better identification of the distal CS activation. These potentials resulted from the sensing of the adjacent LA activation wavefront on both sides of a blocked MI line (Figure 3A).

Pattern 2 (n=5; 19%): as in pattern 1, a distinct pattern of the staggered activation recorded on the distal CS could be identified which was instead in the same direction as the activation recorded on the proximal CS portion (either proximal to distal or distal

to proximal; Figure 3B). In these cases, the stepped activation resulted from the slow conduction through the MI line and, in most cases (n=4), a perimitral AT was diagnosed with the split potentials outlining the gap on the MI line.

Pattern 3 (n=11; 41%): as against the patterns 1 and 2, the stepped activation consisted of double potentials whose far-field components were recorded simultaneously on ≥2 bipoles with no discernable activation pattern. These potentials resulted from far-field LA appendage sensing rather than from the adjacent LA as in patterns 1 and 2 (Figure 3C). In this pattern, MI line conduction could not be anticipated; in about one third of cases (n=4), the MI line was blocked, whereas in the remaining cases, the stepped activation was related to conduction delays through either the MI line or the LA appendage.

### CS Activation Pattern in Macroreentrant AT

The activation patterns observed in perimitral reentry were from distal to proximal (clockwise) in 62% (n=41) and from proximal to distal (counterclockwise) in 38% (n=25). In roof-dependent reentry, the activation patterns were from proximal to distal in 43% of ATs (n=13), chevron/reverse chevron in 30% (n=9), and from distal to proximal in 27% (n=8). The CS activation was from proximal to distal in all CTI-dependent reentries (n=20).

### Probability of AT Mechanism and Localization According to the CS Activation Pattern

The probability of AT diagnosis according to the patterns of CS activation is illustrated in Figure 4.
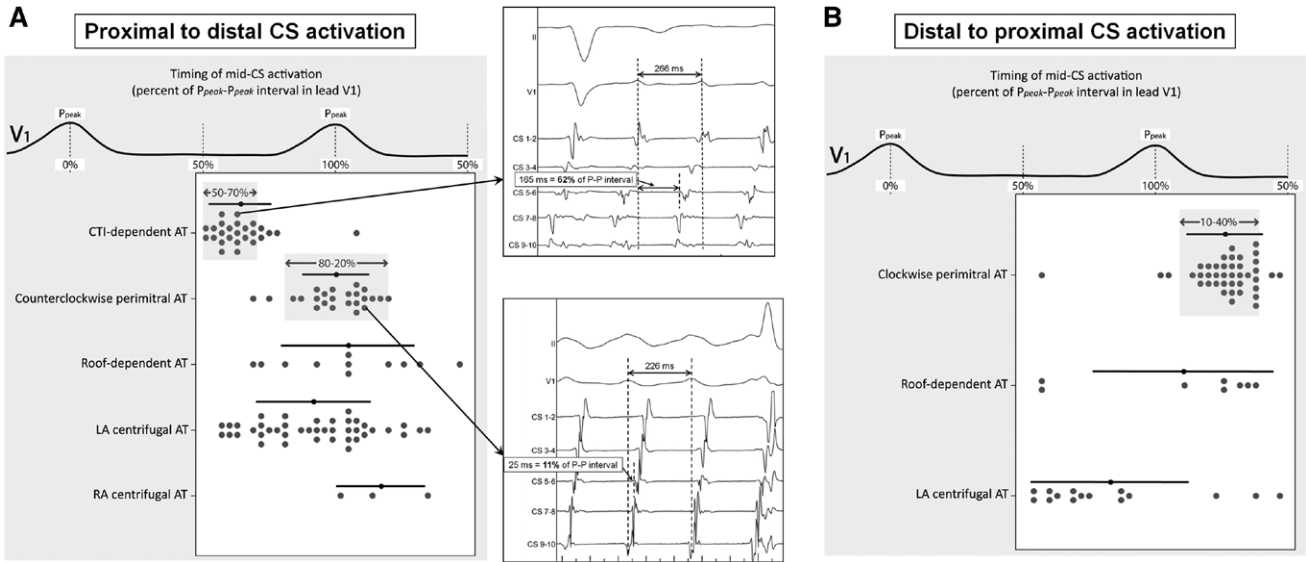
**Figure 5.** Scatterplot showing the individual values of the mid-coronary sinus (mid-CS) activation timing for each atrial tachycardias (AT) mechanism and for proximal to distal (**A**) and distal to proximal (**B**) CS activation. **A**, **Right**, **Top**, Mid-CS activation timing in a cavotricuspid isthmus (CTI)–dependent AT: the activation of the mid-CS follows the mid-$P_{peak}$–$P_{peak}$ (mid-P–P) interval with a calculated ratio of 62%. **Bottom**, Counterclockwise perimitral AT: the mid-CS activation immediately follows $P_{peak}$ with a calculated ratio of 11%. LA indicates left atrial; and RA, right atrial.

In patients with proximal to distal CS activation, the whole range of possible AT mechanisms was observed (Figure 4A). Right centrifugal ATs accounted for only 4% of cases. Consistent with the CS activation pattern, a clustering of the left centrifugal AT foci was observed on the septal side of the posterior LA (and CS). However, foci were widely distributed over the anterior wall, including lateral foci, owing to the presence of MI block in 14% of the centrifugal ATs (Figure 4A, right).

In distal to proximal CS activation (Figure 4B), the majority (61%) of diagnosed ATs were clockwise perimitral ATs (n=41, including 3 figure-of-8 with a roof-dependent loop). Consistent with the CS activation, centrifugal AT foci were exclusively localized on the lateral LA (Figure 4B, right).

In chevron CS activation (Figure 4C), the only macro-reentrant AT observed was roof-dependent reentry which represented 17% of cases. Mapping consistently revealed a descending activation of the posterior LA wall (Figure 4C, right). The remaining 83% were centrifugal ATs originating exclusively from the posterior wall (including CS and roof).

Similarly, in reverse chevron activation (Figure 4D), macroreentrant ATs were roof dependent with 1 atypical reentry around the LA appendage (36%). Mapping of macroreentrant ATs consistently demonstrated a descending activation of the anterior LA wall (Figure 4D, right). The remaining 64% were centrifugal ATs originating exclusively from the anterior wall (including the roof).

## Timing of CS Activation and Mechanism of AT
The delay from the surface P wave ($P_{peak}$) recorded in lead V1 to the local activation recorded on bipoles CS 5-6 could be analyzed in 97% of ATs. In centrifugal ATs, irrespective of the CS activation pattern, the timing of mid-CS activation was heterogeneous and spanned across the whole range of tachycardia cycle. Similarly, variable mid-CS activation timings were recorded in roof-dependent reentry. However, for other macroreentrant ATs, similar timings of CS activation were consistently observed among the study population: mid-CS activation occurred at 61±13%, 0±13%, and 29±11% of the $P_{peak}$–$P_{peak}$ interval, for peritricuspid, counterclock-, and clockwise perimitral AT, respectively. The use of simple discriminant ranges of timings could help identify these macroreentrant ATs.

### Proximal to Distal CS Activation
A mid-CS activation at 50% to 70% of the $P_{peak}$–$P_{peak}$ interval (ie, following the mid-$P_{peak}$–$P_{peak}$ interval; n=30; 14%) identified a peritricuspid AT with a positive and negative predictive value of 70% and 93%, respectively (sensitivity 81% and specificity 89%). A mid-CS activation at 80% to 99% or 0% to 20% of the $P_{peak}$–$P_{peak}$ interval (ie, during the surface P wave; n=54; 24%) identified counterclockwise perimitral AT with a sensitivity of 92%. A limited specificity was, however, observed (61%) because of the wide overlap with other AT mechanisms (positive and negative predictive value of 41% and 91%, respectively; Figure 5A).

### Distal to Proximal CS Activation
A mid-CS activation at 10% to 40% of the $P_{peak}$–$P_{peak}$ interval (ie, immediately following $P_{peak}$; n=44; 20%) identified a clockwise perimitral AT with a positive and negative predictive value of 82% and 75%, respectively (sensitivity 88% and specificity 75%; Figure 5B).

## Discussion

### Main Findings
Our study demonstrates that a simple categorization of the patterns of CS activation could significantly narrow the differential diagnosis of macroreentrant ATs and aid localization of centrifugal ATs. Notably, in chevron and reverse chevron patterns, macroreentries were almost exclusively roof dependent and
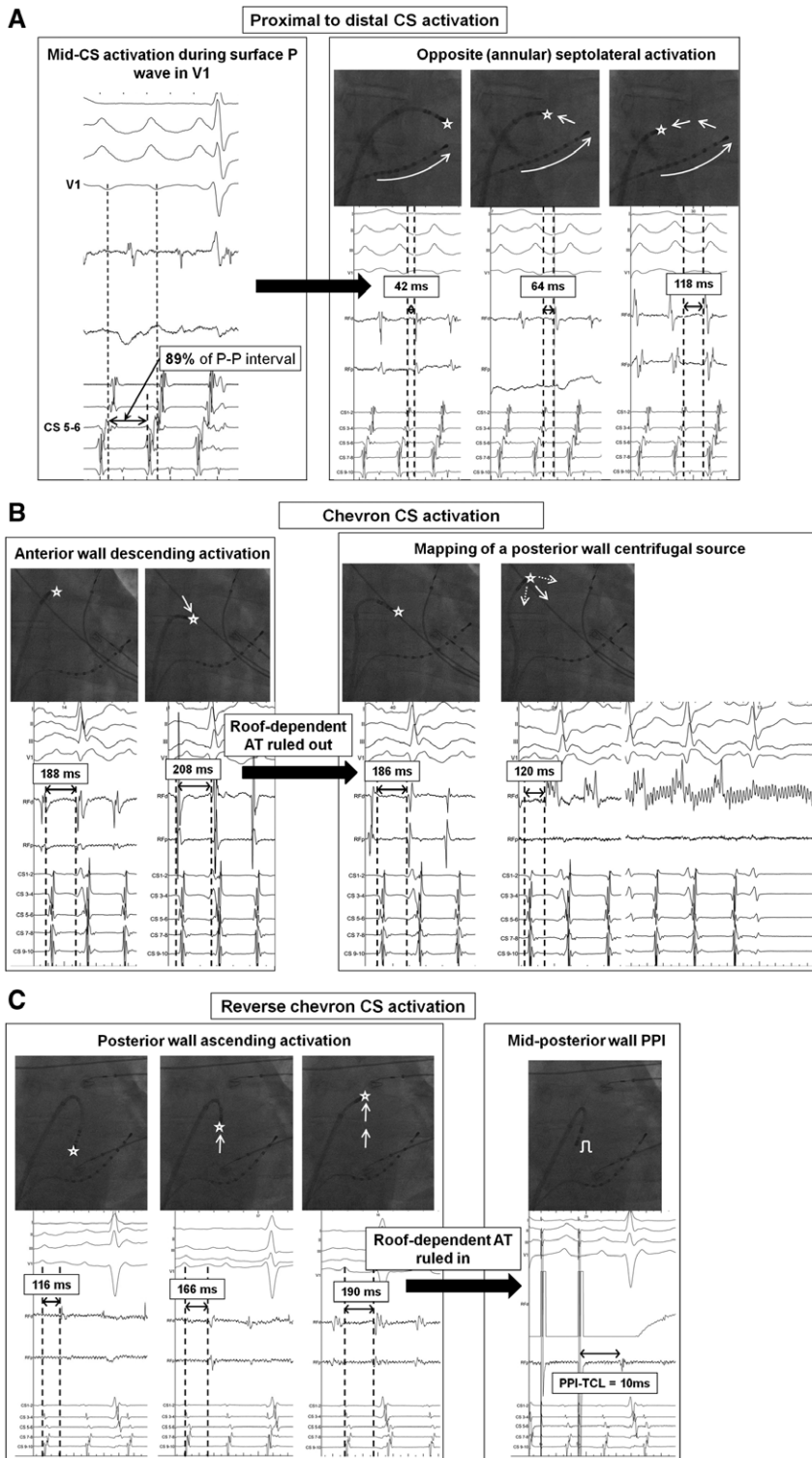
**Figure 6.** Mapping strategy based on the coronary sinus (CS) activation. **A**, Proximal to distal CS activation. Step 1: the mid-CS activation occurs during the surface P wave in V1 (calculated ratio 89%) making a CTI-dependent atrial tachycardias (AT) unlikely. Step 2: the 2-axis segmental left atrial (LA) activation mapping is performed: using CS 1 to 2 as a reference, and moving the RF catheter, the local activation time is obtained at the lateral, mid-, and septal anterior mitral annulus. This allows to identify a lateral to septal activation of the anterior annular LA segment, ie, opposite to the posterior annular LA activation. Counterclockwise perimitral AT is, therefore, ruled in later confirmed by entrainment maneuvers. **B**, Chevron CS activation pattern. Step 1: using CS 5-6 as a reference, the local activation time is obtained at the high and low anterior wall. This allows to identify a descending anterior wall activation, therefore, ruling out a roof-dependent AT. Step 2: the earliest activation site of a centrifugal source is mapped on the posterior wall using the same technique. A descending posterior wall activation is observed with the earliest local activation time identified on the roof. Ablation at this site successfully restored sinus rhythm. **C**, Reverse chevron pattern. Step 1: using CS 1-2 as a reference, the local activation time is obtained at the low-, mid-, and high-posterior wall. This allows to identify an ascending posterior wall activation which rules in a roof-dependent AT. Step 2: entrainment maneuvers (shown on the mid-posterior wall) confirmed a roof-dependent AT. PPI indicates postpacing interval; and TCL, tachycardia cycle length.

mapping of centrifugal sources may be restricted to the posterior and anterior LA wall, respectively. Moreover, our study shows that despite extensive ablation, the timing of the mid-CS activation referenced to the surface P wave in V1 is remarkably constant for perimitral and peritricuspid AT. As a consequence, using a simple approach that integrates the analysis of both the pattern and the timing of CS activation, a mapping strategy can be deducted to select the most relevant activation and entrainment mapping maneuvers that should be undertaken first in more than one half of the cases.

## Background for a More Deductive Mapping Strategy

Our study shows that more than one half of the ATs occurring during or after persistent AF ablation are macroreentrant ATs (56%). The vast majority of them (98%) involved a circuit
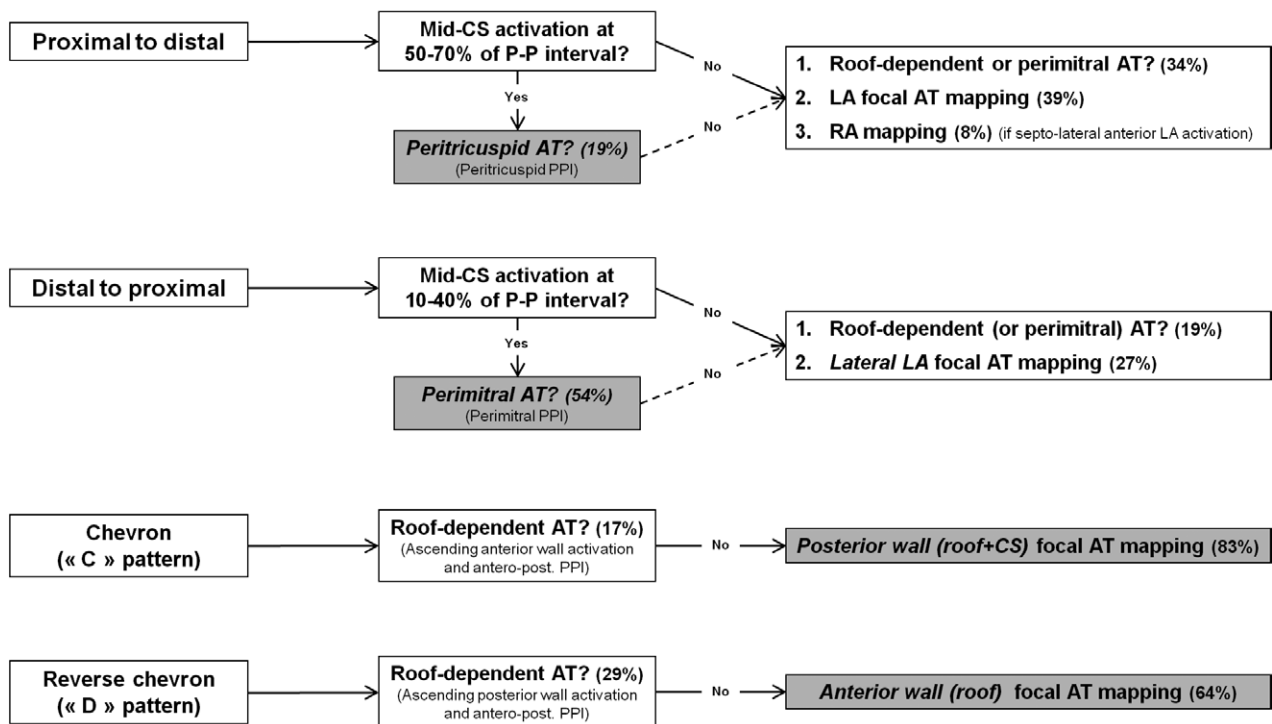
## Coronary sinus activation



**Figure 7.** Stepwise algorithm of atrial tachycardias (AT) mapping based on the pattern and timing of coronary sinus (CS) activation. LA indicates left atrial; PPI, postpacing interval; and RA, right atrial.

around ≥1 of these 3 fixed obstacles: ipsilateral pulmonary veins (left or right), the mitral and the tricuspid annulus. Centrifugal ATs mainly originating from the LA represented the remaining cases. The observation that only 3 types of macroreentrant circuits represent the majority of ATs after persistent AF ablation provides an opportunity to implement more pragmatic mapping strategies.

The complexity of mapping often resides in the multiple areas with extensive voltage reduction and multiple component EGMs with altered sequence of activation. In these situations detailed mapping may prove either difficult or confusing and will often impose the operator to take a step back to concentrate his initial mapping on few selected points. A focused activation mapping of the anterior and posterior LA wall will allow to rapidly narrow the differential diagnosis and find the region of interest.[8] For this purpose, the analysis of the CS recordings provides immediate segmental activation mapping of the inferior (annular) posterior LA wall. Depending on the inferior LA activation pattern, our study shows that major differences in the AT mechanisms and localizations exist. These differences can be taken as an opportunity to individualize the mapping strategy.[9]

### Pitfalls in the Analysis of the CS Activation: The Nonuniform Patterns
A potential drawback of the CS activation pattern analysis lies in the interpretation of sometimes complex EGMs. A nonuniform CS activation pattern was identified in 25% of cases.

About half of them were related to disparate LA-CS activation as a consequence of partial LA-CS disconnection because of previous ablation.[7] Failure to carefully inspect CS potentials at an adequate scale can easily mislead the operator considering that the more apparent CS muscle activation sequence is in fact opposite to the clinically more relevant LA activation.

A stepped CS activation was observed in the remaining half, either alone or in combination with disparate LA-CS activation. The recording of a delayed activation of the 2 LA segments overlying the split CS potentials is often considered to result from sensing on both sides of a blocked MI line. In contrast, our study shows that the MI line was not blocked in ≈40% of such cases. Moreover, our study shows that stepped CS activation does not necessarily add to the complexity of CS interpretation but could instead be used as a diagnostic opportunity. In 60% of cases, a distinct pattern of activation of the far-field components of the double potentials could be identified (patterns 1 and 2). In such cases, the presence of a MI block (opposite activation) or a MI gap with slow conduction (parallel activation) could be diagnosed. In the latter, perimitral reentries were almost exclusively diagnosed with termination of the AT during ablation on the gap outlined by the split potentials recorded on the CS catheter.

### Timing of CS Activation to Guide the Mapping Strategy
Our study shows that the analysis of the CS activation timing with respect to the surface P wave in lead V1 provides a useful guide to the diagnosis of most peritricuspid and perimitral

ATs, despite previous substrate ablation and the creation of lines of block. These findings probably relate to the fact that the P wave in reference lead V1 mainly results from the activation of the right atrium and its appendage especially after extensive LA ablation. The similar CS-right atrium timing sequence of activation, therefore, probably derives from the fact that both reentries are circuits around fixed anatomic obstacles located either in the right atrium or along the CS. However, most peritricuspid ATs observed after persistent AF ablation were counterclockwise reentries. As a consequence, considering the expected differences in the CS-right atrium activation sequence, our findings may be less applicable to a selected population with clockwise peritricuspid AT.

## Categorization of the CS Activation Patterns and Timing to Rationalize the Mapping Strategy

### *Proximal to Distal CS Activation*

This pattern is the most nonspecific pattern as the whole range of AT mechanism and location should be considered. However, whenever the mid-CS activation occurs at 50% to 70% of the $P_{peak}$–$P_{peak}$ interval (ie, following the mid-$P_{peak}$–$P_{peak}$ interval), most peritricuspid ATs will be indentified with good specificity. The first mapping step will, therefore, be to rule-out this diagnosis by appropriate mapping and entrainment maneuvers. This single step will provide the diagnosis in ≈20% of cases and, if negative, will allow the operator to concentrate his mapping in the LA. This is all the more relevant considering that in the setting of markedly abnormal atrial substrate after AF ablation, CTI-dependent AT rarely manifests with a typical saw-tooth appearance on 12-lead ECG.[10] Focused segmental LA activation mapping should be performed next to exclude the most frequent LA macroreentries.[8] For this purpose, the 2-axis activation of both the anterior and the posterior LA wall is first considered: the vertical axis activation (ascending or descending wavefront) and the septolateral axis activation of its annular segments (Figure 6A). A lateral to septal anterior mitral annulus activation (ie, opposite to the CS activation) will rule in perimitral AT, whereas an opposite anterior/posterior wall vertical activation will rule in roof-dependent AT. Appropriate entrainment maneuvers to confirm 1 or the other diagnosis will be performed. If both macroreentries are ruled out, the operator will concentrate his mapping on searching for the earliest activation of a LA focal source guided by the 2-axis activation mapping. A right atrial origin will be considered in case of consistent LA mapping (ie, septal to lateral anterior activation). Our study shows that most centrifugal sources are located on the septal half of the LA (including the CS; 81%). However, a source from the lateral anterior wall should also be considered as a previous block (or slow conduction) across the MI line will also result in a proximal to distal CS activation, despite the lateral origin.[9] As discussed, a stepped CS activation will provide a clue in such situations.

### *Distal to Proximal CS Activation*

This pattern is related to clockwise perimitral AT in the majority of cases (61%). The mapping strategy should, therefore, first aim at ruling in or out this possibility. Our study shows

that the analysis of the timing of the mid-CS activation with respect to the surface P wave in lead V1 can aid in identifying most perimitral ATs with good specificity. Accordingly, whenever mid-CS activation occurs at 10% to 40% of the $P_{peak}$–$P_{peak}$ interval (ie, immediately follows the $P_{peak}$ in V1), the first mapping step should be to rule-out perimitral AT by appropriate entrainment maneuver. This selectively applied pacing maneuver will provide the diagnosis in more than half of distal to proximal ATs (54%). In the remaining cases, the 2-axis segmental LA activation mapping of both the anterior and the posterior LA will be performed. Only the vertical axis of activation (ie, ascending or descending) will be assessed for those cases where perimitral AT has been ruled out. If roof-dependent AT is ruled out, mapping can concentrate on searching for the earliest activation of a focal source on the lateral part of the LA guided by the previously assessed vertical axis activation.

### *Chevron CS Activation*

This pattern results from a posterior centrifugal, or descending, activation wavefront. As a consequence, perimitral and CTI-dependent AT are excluded and the only macrorentrant AT observed was roof dependent. A pragmatic approach would, therefore, be to first exclude this diagnosis. Considering that only an ascending activation of the anterior wall will rule-in the diagnosis of roof-dependent AT (ie, opposite to the posterior wall), only limited mapping of the anterior wall is required (Figure 6B). In the event of opposite vertical activation of both walls, selective entrainment will rule-out or confirm the diagnosis. If roof-dependent AT is ruled out, further mapping can concentrate on searching for the earliest activation of a focal source on the posterior wall (including the roof and CS).

### *Reverse Chevron CS Activation*

This pattern results from an anterior centrifugal, or descending, activation wavefront. As a consequence, perimitral AT is excluded and no peritricuspid AT was observed. Although unlikely, the diagnosis of CTI-dependent reentry cannot formally be excluded because previous reports have shown the possible occurrence of reverse chevron pattern in clockwise peritricuspid AT.[11,12] In these cases, the LA is predominantly activated over the Bachmann's bundle as opposed to the CS ostium. Similar to the chevron pattern the first step will be to rule-out a roof-dependent AT. An ascending activation of the posterior wall will rule this diagnosis in (ie, opposite to the anterior wall) confirmed or not by entrainment maneuvers (Figure 6C). If roof-dependent AT is ruled out, the operator will be able to concentrate on searching for the earliest activation of a focal source on the anterior wall (including the roof).

A summary of proposed initial mapping steps based on the CS activation patterns and timing is illustrated in Figure 7. The AT mechanism and localization may be provided in nearly half of the patients using only focused mapping of 1 LA segment or the evaluation of the CS activation timing.

## Study Limitations

The stepwise ablation approach performed in the study population included EGM-guided and LA linear lesions. Because the prevalence of both the type and the localization of AT is

closely related to the ablation strategy adopted, these findings may less apply in a patient population where a more conservative strategy is undertaken. However, the same assumption strengthens the potential value of a pattern-based strategy to guide the initial mapping steps even in more complex underlying atrial substrate.

A variety of atypical macroreentrant ATs other than those reported in our study may occur after persistent AF ablation. These ATs will require more extensive activation and entrainment mapping. However, their prevalence is low considering that only 2 of them were diagnosed (1%), while the mechanism of only 3% of AT could not be elucidated.

Finally, relying on the CS activation pattern implies a proper positioning of the CS catheter, which may occasionally prove difficult.

## Conclusions

The analysis of both the patterns and the timing of CS activation can aid rapid diagnosis of postablation ATs. It provides a rapid stratification of the most likely macroreentrant ATs that should first be ruled out and points toward the likely origin of centrifugal ATs. It can be included in a stepwise diagnostic approach to rapidly select the most critical activation and entrainment mapping maneuvers.

## Disclosures

None.

## References

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## CLINICAL PERSPECTIVE

Mapping of atrial tachycardias (AT) arising after ablation of persistent AF is often challenging, since extensive atrial substrate has been targeted. It is, therefore, critical for the operator to have a preconceived suspicion of possible mechanism and AT location to avoid more exhaustive and sometimes confusing mapping. In this regard, the analysis of the standard multipolar coronary sinus (CS) recordings provides a unique opportunity to rapidly guide the operator by providing immediate segmental activation mapping of the inferior posterior left atrial (LA) wall. Pragmatic mapping strategies may further be implemented based on the observation that the vast majority of macroreentrant ATs involve 1 out of 3 types of circuits (perimitral, peritricuspid, and roof-dependent). Out of 223 ATs, our study demonstrates that a simple categorization of the patterns of CS activation could significantly narrow the differential diagnosis of macroreentrant ATs and aid localization of centrifugal ATs. Notably, in chevron and reverse chevron CS activation patterns, macroreentries were almost exclusively roof-dependent, and mapping of centrifugal sources may be restricted to the posterior and anterior LA wall, respectively. Moreover, our study shows that despite extensive ablation, the timing of the mid-CS activation referenced to the surface P wave in V1 is remarkably constant for perimitral and peritricuspid AT. As a consequence, using a simple approach that integrates the analysis of both the pattern and timing of CS activation, a stepwise mapping strategy can be deducted to select the most critical activation and entrainment mapping maneuvers that should be undertaken first.