Visualizing Localized Reentry With Ultra–High Density Mapping in Iatrogenic Atrial Tachycardia
Beware Pseudo-Reentry

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Background—The activation pattern of localized reentry (LR) in atrial tachycardia remains incompletely understood. We used the ultra–high density Rhythmia mapping system to study activation patterns in LR.

Methods and Results—LR was suggested by small rotatory activations (carousels) containing the full spectrum of the color-coded map. Twenty-three left-sided atrial tachycardias were mapped in 15 patients (age: 64±11 years). 16253±9192 points were displayed per map, collected over 26±14 minutes. A total of 50 carousels were identified (median 2; quartiles 1–3 per map), although this represented LR in only n=7 out of 50 (14%): here, rotation occurred around a small area of scar (<0.03 mV; 12±6 mm diameter). In LR, electrograms along the carousel encompassed the full tachycardia cycle length, and surrounding activation moved away from the carousel in all directions. Ablating fractionated electrograms (117±18 ms; 44±13% of tachycardia cycle length) within the carousel interrupted the tachycardia in every LR case. All remaining carousels were pseudo-reentrant (n=43/50 [86%]) occurring in areas of wavefront collision (n=21; median 0.5; quartiles 0–2 per map) or as artifact because of annotation of noise or interpolation in areas of incomplete mapping (n=22; median 1, quartiles 0–2 per map). Pseudo-reentrant carousels were incorrectly ablated in 5 cases having been misinterpreted as LR.

Conclusions—The activation pattern of LR is of small stable rotational activations (carousels), and this drove 30% (7/23) of our postablation atrial tachycardias. However, this appearance is most often pseudo-reentrant and must be differentiated by interpretation of electrograms in the candidate circuit and activation in the wider surrounding region. (Circ Arrhythm Electrophysiol. 2017;10:e004724. DOI: 10.1161/CIRCEP.116.004724.)

Key Words: atrial fibrillation ■ cardiac electrophysiology ■ fibrosis ■ tachycardia, supraventricular

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WHAT IS KNOWN
• Localized reentrant atrial tachycardia (LR-AT) is presumed to involve slow conduction and reentry around postablation scar, characterized by long duration and fractionated electrograms within the circuit.
• The activation pattern of LR remains incompletely understood owing to the limited number of points and electrogram resolution acquired with most mapping systems, and the difficulty annotating activation times in areas of slow conduction.

WHAT THE STUDY ADDS
• Using ultra-high density mapping and small electrodes with narrow interelectrode spacing, LR appeared as stable and continuous rotations around small islands of scar <0.03 mV, with electrograms that encompassed the full tachycardia cycle length with each rotation, ablation of which terminated AT.
• Small rotational activations were more commonly pseudoreentrant, occurring in areas of wavefront turning and collision, or as artifact due to annotation of noise or interpolation in areas of incomplete mapping.
• This study offers a methodology for differentiating true from pseudoreentrant activation.

for activation mapping. This has enabled a better understanding of different tachycardia circuitry, especially within low-voltage myocardium. In this study, we hypothesized that the system could accurately delineate the activation of LR in iatrogenic ATs as a guide to ablation.

Methods
Patients with symptomatic ATs after previous atrial fibrillation (AF) ablation referred to our center and mapped with Rhythmia were studied. The catheter and mapping system has been previously described in detail. The study was approved by an institutional review committee, and all subjects gave informed consent.

Procedures were conducted under general anesthesia. A decapolar catheter was placed in the coronary sinus and used as a stable reference to time local activation in tachycardia. Transseptal access was gained to the left atrium using transesophageal echocardiography, and the Orion catheter and ablation catheter were supported using long sheaths. Unfractionated heparin was administered before insertion of the Orion catheter through an 8.5F sheath and continued to maintain an activated clotting time >300 seconds throughout.

The geometry of the cardiac chambers was acquired based on the location of the outermost electrodes of the basket using in-built magnetic and impedance sensing. Mapping was performed in tachycardia, seen either from the start or induced with atrial burst pacing. The system calculated the median TCL over 10 seconds and set the default threshold of 0.03 mV used in this study, and areas below this confidence threshold were displayed in gray and defined as scar. Reducing this value below <0.03 mV reduced the gray zone size.

Theoretically, LR should demonstrate continuous rotation within a small area, with each rotation encompassing one full TCL. We identified all putative LR sites as those with apparent continuous rotational activation around an area <2 cm (based on the mapping field of the multispline catheters in which LR was originally mapped). We labeled these rotational patterns as carousels. These sites spanned the full spectrum of the color-coded map, with an early (red) meets late (purple) site. An example is illustrated in Figure 1 and Movie I in the Data Supplement. For each putative LR site, the electrograms along the rotation were studied. We defined LR where:

1. Electrograms could be tracked around the circuit and spanned the complete TCL without any unaccounted for isoelectric period.
2. Activation moved away from the circuit in all direction.
3. The appearance of rotation was consistent between unipolar and bipolar local activation time maps.
4. Termination of tachycardia with ablation within the circuit.

Entrainment maneuvers were generally avoided because of the risk of transforming or terminating the tachycardia and because local capture within low-voltage areas may have proved difficult. A fractionated electrogram within the circuit was targeted for ablation. Power-controlled (25–35 W) radiofrequency energy was delivered (Stockert 70 RF generator; Biosense Webster) through an irrigated ablation catheter (17 mL/min) with a target temperature of 48°C.

Statistics
Categorical variables were expressed as percentages. Continuous variables were expressed as mean±1 SD for data with symmetrical distributions and medians with first and third quartiles for skewed distributions.

Results
A total of 23 left ATs were fully mapped in 15 patients (age 64±11 years) using ultra–high density (16253±9192 points displayed per map). Each patient had undergone previous AF ablation (pulmonary venous isolation [100%], roof line 8/15 [53%], mitral isthmus line 5/15 [33%], electrogram defragmentation 5/15 [33%]), and 11 out of 15 patients (73%) had...
undergone ≥2 ablation procedures including 5 out of 15 patients (33%) for a previous AT. The mean AT cycle length mapped was 279±76 ms, 8 of which were induced (either initially or after termination of a different AT). The mean LA volume was 133±37 mL, collected from 2197±1649 beats over an average mapping time of 26±14 minutes.

We identified n=50 carousels (median 2; quartiles 1–3 per map) in these 23 maps. Table 1 summarizes the clinical details, procedure history, and the number of carousels per patient.

Three distinct carousel types were identified, and a decision tree to classify carousel activation is presented in Table 2.

**Type 1 Carousel—Localized Reentry**

This was observed in n=7/50 carousels (14%). Examples are presented in Figures 2 and 3 and Movies II and III in the Data Supplement. Electrograms tracked around the circuit encompassed the full TCL. Of these 7 carousels, n=6 seemed to rotate around an area of probable scar, colored gray in the map, defined by guest on December 10, 2017 http://circep.ahajournals.org/ Downloaded from

### Table 1. Clinical Details, Procedure History, and the Number of Carousels per Patient

<table>
<thead>
<tr>
<th>Patient</th>
<th>Previous Procedures</th>
<th>Previous Ablation</th>
<th>LA Volume, mL</th>
<th>AT Maps</th>
<th>Total Carousels</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>PVI+roof+MI</td>
<td>111</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>PVI+CFAE+roof</td>
<td>124</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>PVI+CFAE+MI</td>
<td>132</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>PVI</td>
<td>128</td>
<td>2</td>
<td>13</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>PVI+roof+anterior MI+anterior isthmus</td>
<td>120</td>
<td>1</td>
<td>2</td>
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<tr>
<td>6</td>
<td>4</td>
<td>PVI+CFAE+floor+septum+GPs</td>
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<td>1</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>3</td>
<td>Surgical AF (Epicor)+LAA+RPV</td>
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<td>1</td>
<td>0</td>
</tr>
<tr>
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<td>2</td>
<td>PVI+CFAE</td>
<td>99</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>9</td>
<td>2</td>
<td>PVI+anterior isthmus+roof</td>
<td>162</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>PVI+MI</td>
<td>134</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>11</td>
<td>1</td>
<td>Roof line</td>
<td>178</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td>Roof line+LLPV isolation</td>
<td>203</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>13</td>
<td>2</td>
<td>PVI+roof+CFAE</td>
<td>148</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>14</td>
<td>1</td>
<td>PVI</td>
<td>117</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>15</td>
<td>2</td>
<td>PVI+MI+roof</td>
<td>228</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

AT indicates atrial tachycardia; CFAE, complex fractionated atrial electrogram; LA, left atrium; LLPV, left lower pulmonary vein; MI, mitral isthmus; and PVI, pulmonary venous isolation.
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by a peak amplitude <0.03 mV or inconsistent activation timing between neighboring points. The size of the scar was found to be smaller than that suggested in previous studies (maximum diameter 12±6 mm; median surface area 44 mm² [quartiles=31–55]).

The remaining n=1 rotated through 2 distinct gaps along a line of block (2 cm in length). Conduction velocity around the scar varied in accordance with degree of fractionation along the carousel. The activation wavefront in the wider area around the

![Table 2. A Summary of the Different Carousel Types and Their Distinguishing Features](image)

<table>
<thead>
<tr>
<th>Category</th>
<th>Type I—Localized Reentry</th>
<th>Type II—Pseudo-Reentry</th>
<th>Type III—Artifact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macroscopic activation</td>
<td>Moves away in all directions</td>
<td>Incoming wavefront from elsewhere observed to head into the carousel and advance activation around it</td>
<td>Interpolation in areas of low density</td>
</tr>
<tr>
<td>Core (scar threshold &lt;0.03 mV)</td>
<td>Area of gray ≈1 cm</td>
<td>Pinwheel or area of gray</td>
<td>Pinwheel</td>
</tr>
<tr>
<td>Cycle length mapped</td>
<td>EGMs around carousel encompass full TCL</td>
<td>EGMs cannot be tracked around TCL because of unaccounted isoelectric period between split potentials</td>
<td>Annotion encompasses TCL by chance</td>
</tr>
<tr>
<td>Electrograms</td>
<td>Fractionation within carousel usually critical site for ablation</td>
<td>Overlapping regions of split or fractionated potentials coinciding with wavefront collision</td>
<td>Unipolar/bipolar EGMs suggestive of poor catheter contact, noise, or movement artifact</td>
</tr>
<tr>
<td>Map annotation display</td>
<td>Consistent pattern on bipolar and unipolar display</td>
<td>Consistent pattern on bipolar and unipolar display</td>
<td>Inconsistent pattern on bipolar and unipolar annotation display</td>
</tr>
<tr>
<td>Trouble shooting</td>
<td>...</td>
<td>Careful interpretation of collision point and appreciation of split potentials</td>
<td>Can be removed by adjusting the confidence mask</td>
</tr>
</tbody>
</table>

EGM indicates electrogram; and TCL, tachycardia cycle length.

by peak amplitude <0.03 mV or inconsistent activation timing between neighboring points. The size of the scar was found to be smaller than that suggested in previous studies (maximum diameter 12±6 mm; median surface area 44 mm² [quartiles=31–55]).

The remaining n=1 rotated through 2 distinct gaps along a line of block (2 cm in length). Conduction velocity around the scar varied in accordance with degree of fractionation along the carousel. The activation wavefront in the wider area around the

Figure 2. A patient with previous pulmonary venous isolation and electrogram defragmentation for persistent atrial fibrillation, as well as linear lesions for both perimital and roof-dependent atrial tachycardias (ATs) underwent redo atrial tachycardia (CL 280 ms) ablation (Movie II in the Data Supplement). The previous perimital AT was treated with 2 lines (LLPV, posterior mitral annulus; RSPV, anterior mitral annulus) and the roof-dependent AT with an anterior roof line. A. The original roof line appeared incomplete as suggested by the ablation tags, (B) with the potential to set up localized reentry (LR). C, 28,365 electroanatomic points were collected in 41 min. D, The activation map showed the full color spectrum rotating counterclockwise around a small island of scar (12 mm, 55 mm²) on the anterior wall, akin to a carousel. E, Electrograms sampled around this small circuit (1–6) contained low voltage (0.05–0.15 mV) and fractionated signals, and electrograms could be tracked around the circuit covering the full cycle length. Ablation delivered within the circuit terminated AT. Notably, some of the fractionation in electrogram (EGM) 3 is likely bystander, as it extends beyond local signal at EGM 4 and 5. LAA indicates left atrial appendage; LLPV, left lower pulmonary vein; LUPV, left upper pulmonary vein; MA, mitral annulus; RLPV, right lower pulmonary vein; and RUPV, right upper pulmonary vein.
carousel moved away in all directions. Carousel activation was consistent at the same site on both unipolar and bipolar display (as illustrated in the figures in the Data Supplement corresponding to Figures 2 and 3). The most fractionated electrogram along the carousel (117±18 ms; 44±13% of TCL) was ablated resulting in termination of AT in every case, confirming that this activation was consistent with LR. Figure 2 illustrates how iatrogenic LR can occur after previous ablation.

Type II Carousel—Pseudo-Reentry

This was observed in n=21/50 carousels (42%; median 0.5; quartiles 0–2 per map, identified in 8/23 AT maps). Examples are presented in Figures 4 and 5 and Movies IV and V in the Data Supplement. As the head of an activation wavefront entered a region of low voltage, it slowed and curved around this site. A secondary wavefront was seen to enter this region from elsewhere, colliding with the head of the primary wavefront and advancing activation around it. This complex wavefront interaction created a visual impression of rotation, which we classified as pseudo-reentrant. This carousel was characterized by overlapping regions of split or fractionated potentials coinciding with wavefront collision, highlighted by the color heterogeneity of the points annotated within this region (indicative of adjacent electrograms with different activation timings). Electrograms could not be tracked around the full TCL, because of the unaccounted for isoelectric period between the split potentials. All electrogram signals were real; hence, the carousel activation was consistent at the same site on both unipolar and bipolar activation maps (as illustrated in the figures in the Data Supplement corresponding to Figures 4 and 5). These carousels were misdiagnosed as localized reentrant in 5 cases and inappropriately ablated (an example is illustrated in Figure 5).

Type III Carousel—Artifact

This was observed in n=22/50 carousels (44%; median 1; quartiles 0–2 per map, identified in 10/23 AT maps). A
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The pinwheel was often present at the center of rotation. These occurred because of annotation of artifact signal in areas of incomplete mapping. Less detailed mapping was performed immediately adjacent to the mitral annulus and isolated pulmonary veins, where these carousels were typically found. As illustrated in Figure 6 and Movie VI in the Data Supplement, just 3 points with different local activation times across the WOI can create the appearance of continuous rotation because of interpolation of activation between these sites. Figure 7 and Movie VII in the Data Supplement illustrates how annotation of noise was able to create carousel activation near the mitral annulus. Real electrograms could not be tracked around the full TCL. Carousel activation was inconsistent between unipolar and bipolar activation maps (as illustrated in the figures in the Data Supplement corresponding to Figures 7). In many of these carousels, activation could be observed heading into them from elsewhere. These carousels were easily recognizable as an interpolation error and never ablated.

Further examples of each carousel type are presented within Movies VIII through X in the Data Supplement.

Discussion

This study used ultra–high density mapping with increased electrogram resolution to characterize the activation pattern of LR in AT. Activation appeared as a stable and continuous rotation around a small island of scar (≈1 cm in diameter) that encompassed the full TCL. However, this pattern of activation had poor specificity and more commonly occurred in areas of wavefront turning and collision or because of annotation of artifact. This study illustrates how both the electrograms in the candidate circuit and activation in the wider surrounding region are necessary to distinguish pseudo-reentry from LR.

Extensive left atrial ablation in the treatment of persistent AF is associated with future AT. Areas of recovery will conduct slowly, manifest by electrogram fractionation, and support the initiation and sustainability of LR. Mapping
localized reentry within regions of slow conduction has been limited by the resolution of electrogram signals recorded by conventional mapping catheters. Furthermore, limited point density on previous mapping systems resulted in large areas of activation interpolation, and localized reentrant circuits often appeared as focal.4,5,15,16 Studies with multispline catheters suggested that LR involves reentry around an area of scar <2 cm in diameter, corresponding to the mapping field of these specific catheters. The Rhythmia mapping system offers ultra–high density electroanatomic mapping with increased electrogram resolution.17 Combining 64 small electrodes with narrow interelectrode spacing (0.4 mm²; 2.5 mm center-to-center spacing) and a point density >10-fold that of conventional maps, it facilitates the differentiation of active from nonconductive tissue within low-voltage areas, critical to studying LR.9,10,18 Using this system, we have been able to

Figure 5. A further example of pseudoreentry from a patient with multiple previous ablations and stable atrial tachycardia (AT; CL 260 ms; Movie V in the Data Supplement). Carousel activation was seen on the anterior wall near an area of low-voltage tissue, rotating around a pinwheel. This is captured in the static local activation time (LAT) map (top left) and magnified (top center). This was misdiagnosed as localized reentry (LR) and extensively ablated without change in tachycardia activation (far right). An explanation for pseudoreentry has been illustrated in the timing panels of propagation, which preserves the color coded display and demonstrates the leading edge of the activation waveform in maroon. The dotted arrow represent where activation has been in the preceding timing panels. Between time 0 and 92 ms, a primary wavefront of activation (labeled 1) travelling toward the mitral annulus encountered a line of block (sites 3–5), characterized by a regions of split potentials (electrogram panel). The wavefront turned counterclockwise around this line into a cul-de-sac (site 6). A secondary wavefront (labeled 2) travelling toward this area of low voltage collided with the head of the primary wavefront (starred—site 7) and advanced activation around (site 1–2) creating the impression of reentry. LAA indicates left atrial appendage; LUPV, left upper pulmonary vein; MA, mitral annulus; and RUPV, right upper pulmonary vein.

Figure 6. Carousel activation can be seen from just 3 closely spaced points with different annotation of local activation timing (LAT) across the window of interest (WOI) because of interpolation between these 3 timings (Movie VI in the Data Supplement).
fully characterize the activation pattern of most LR circuits as small rotatory activations around scar ≈1 cm in diameter. We termed this type of activation a carousel. Electrograms could be followed around the circuit and encompassed the full TCL. Ablation at sites of electrogram fractionation within the carousel interrupted the tachycardia in each case. With the expectant incorporation of ultra–high density facilities into most 3-dimensional mapping systems, this pattern of activation will be seen far more frequently.

However, carousels are not specific for LR. In this study, carousels were evident on most maps collected, although represented LR in only a small proportion. The majority of carousels were pseudo-reentrant. Where an activation wavefront curved around an area of nonuniform anisotropy, a critically timed secondary wavefront entering from the opposite direction collided and extinguished the primary wavefront and advanced activation around it, creating the visual impression of rotational activation. On closer inspection, the exact nature of these wavefront interactions was understood, akin to recurrent reset seen during entrainment, an observation facilitated by ultra–high density.19,20 These areas of collision contained overlapping regions of split or fractionated potentials. This appearance was distinct from LR where activation moved away in all directions. Without careful recognition of this phenomenon, operators may be misled to deliver ablation at these pseudo-reentrant sites irrelevant to the clinical tachycardia. Carousels also arose from annotation of artifact or interpolation in areas of incomplete mapping. In fact, a minimum of 3 closely spaced points was sufficient to create this false carousel, where annotation happened to span the WOI. Such an occurrence might be seen in areas of electrogram fractionation (where

the system must assign a single activation time to a multi-component signal), in areas with poor catheter contact and in areas with a low signal to noise ratio.

The voltage threshold to differentiate atrial scar from conducting tissue is unknown. Studies using cardiac magnetic resonance imaging suggested that regions <0.3 mV were consistent with chronically ablated atrial tissue.21 Sites without pace capture (at 10 mA/2 ms) led to a lower suggestion of 0.15 mV.22 The Rhythmia system includes a confidence mask that can be used to visually gray out areas of the map in which the system has a low confidence in its signal annotation because of extremely low voltage, a locally large variation in annotation times, or a mixture of both. Gray areas of the map may, therefore, suggest the presence of scar. Defining scar can be useful when mapping LR, and its accuracy is dependent on the recording technique and noise threshold of the mapping system. The greater fidelity mapping offered by the Rhythmia system allowed us to identify active tissue within areas of low voltage and apply a confidence mask threshold (or scar threshold) of 0.03 mV. This allowed us to identify regions of possible scar with amplitudes 5 to 10 times lower than previous studies about which LR can rotate. However, the confidence threshold is arbitrary; and 0.03 mV was used as a default setting of the system. By reducing the threshold <0.03 mV, the central gray low confidence zone filled with color and gave the false appearance of rotation anchored around a pinwheel. Despite the attraction of focusing ablation at the core of the pinwheel itself, operators should be cognizant that this appearance is an interpolation artifact and that ablation at the exact pinwheel site is unlikely to terminate tachycardia.
This study has indirect implications for mapping of AF. Previous studies have suggested that AF may be driven by small rotational activations, manifest as early-to-late activating spirals with rotational activity around an anchor, akin to the carousels seen in this study.\textsuperscript{1,2}\textsuperscript{1,2} However, localized reentry in AT and rotors in AF are mechanistically different and mapped using different techniques. Despite this difference, the visual impression of small rotational activations seen in both rhythms is similar, perhaps allowing for indirect comparison. The ablation of rotational activation in AF has had mixed clinical benefit.\textsuperscript{25} We have shown that even in stable AT, the majority of rotational activation patterns seen are pseudo-reentrant, associated with complex wavefront interactions. We incorrectly ablated these patterns, believing they represented LR. Wavefront collisions and interactions around lines of block are even more prevalent in a fibrillatory milieu, and this might lead to multiple wannabe reentries being incorrectly labeled as a rotor and incorrectly ablated as well.\textsuperscript{26}

\textbf{Limitations}

This is a single-center study with a limited number of patients. However, this study is not intended to be an experiential description of ultra–high-density activation mapping but rather offers a detailed analysis and pitfalls of identifying rotational activation in areas of low voltage.

We did not perform entrainment maneuvers within the localized reentrant circuit because of this risk of transforming or terminating the clinical tachycardia and because local capture within these low-voltage areas may have proved difficult. A comparison of the response to entrainment within the carousel types would have offered greater understanding of their electrophysiological characteristics. However, our primary aim was to accurately delineate the 3-dimensional activation pattern of LR with ultra–high density.

We used the conventional bipolar voltage metric to define scar, although changes in amplitude of a bipolar signal can occur according to the electrode orientation, wavefront direction, wavefront collision, and atrial rate. Furthermore, there is no practical lower bound on voltage that defines a lack of conduction.

The most fractionated electrograms in these localized circuits were <50% of the full cycle length. A circuit with even longer duration of fractionation might occupy so much of the timing window at a single point that the full color spectrum may not be apparent. These microreentrant circuits may appear focal with slow breakout away from its source.\textsuperscript{3,5}

\textbf{Conclusions}

Ultra–high density mapping is unique in its ability to display the activation of localized reentrant AT in the previously ablated left atrium. Activation is akin to a carousel, rotating around areas of scar (\textapprox 1 cm in diameter), encompassing the full TCL with each rotation. However, carousel activation does not always imply LR and occurs more commonly in areas of wavefront turning and collision or because of annotation of artifact. In the era of ultra–high density mapping of complex arrhythmia, rotational activation patterns should be interpreted with caution.

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\textbf{Disclosures}

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\textbf{References}


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SUPPLEMENTAL MATERIAL

Supplementary Figure

Bipolar (left) and Unipolar (right) LAT displays for each of the AT maps presented in the manuscript.

(a) – corresponds to figure 2

(b) – corresponds to figure 3
(c): corresponds to figure 4

(d) – corresponds to figure 5
(e) -- corresponds to figure 7

Bipolar  
Unipolar
Video legends

**Supplementary video 1: Carousel activation**

A magnified view of carousel activation (continuous rotational activation), played at fast and slow speeds, that appears to rotate around a pinwheel. Activation can be followed by tracking the leading edge of the maroon colored wavefront.

**Supplementary video 2: Type I carousel**

A magnified view of counter-clockwise carousel activation around an island of gray (presumed scar) is followed by the complete propagation map corresponding to figure 2. The carousel is apparent within the mid-anterior wall. Activation wavefronts in the wider surrounding area move away from the carousel in all directions.

**Supplementary video 3: Another Type I carousel**

A further example of a type I carousel, including both magnified and complete propagation maps corresponding to figure 3. This carousel is apparent beneath the left sided pulmonary veins.

**Supplementary video 4: Type II carousel**

A magnified view of apparent carousel activation around a pinwheel, is followed by the complete propagation map corresponding to figure 4. The carousel is evident on the posterior mitral annulus. This is formed by a primary wavefront that turns clockwise through an area of slow conduction. An incoming wavefront from the roof collides with the head of primary wavefront, advancing activation around, creating the impression of complete rotation.
Supplementary video 5: Another type II carousel

A further example of a type II carousel, including both magnified and complete propagation maps corresponding to figure 5. This carousel is apparent on the anterior wall near an area of low voltage tissue, rotating around a pinwheel. A clear wavefront is seen moving into this carousel from the mitral isthmus.

Supplementary video 6: Carousel interpolation

Carousel activation created from 3 closely spaced points with different local activation timing across the window of interest, corresponding to figure 6. Rotation occurs around a pinwheel which itself has no underlying data point.

Supplementary video 7: Type III Carousel

A magnified view of apparent carousel activation around a pinwheel, is followed by the complete propagation map corresponding to figure 7. The location of the erroneous signal within this carousel is highlighted. By removing the noise signal, the propagation map shows the carousel is no longer evident.

Supplementary video 8: Additional examples of a Type I carousel
Includes two further examples of type I carousels. The first rotates around an area of scar on the antero-septum, and the second around two gaps along a line of block beneath the left sided pulmonary veins. A figure illustrating the path of activation and electrograms along each carousel is included within the video.

**Supplementary video 9: Additional examples of Type II carousels**

Includes three further examples of a type II carousel. A star marks the apparent “center of rotation” each around a pinwheel. These occurred near the antero-septum, close to the left atrial appendage, and adjacent to the posterior mitral annulus respectively. In each example, whilst a primary wavefront turns through an area of slow conduction, an incoming wavefront collides with the head of primary wavefront, advancing activation around, creating the impression of a complete rotation.

**Supplementary video 10: An additional example of a Type III carousel**

Includes an additional example of a type III carousel. A star marks the apparent “center of rotation” around a pinwheel. Mis-annotation of noise artifact within an area of incomplete mapping gives the appearance of rotational activation. By re-annotating away from the noise, the propagation map shows the carousel is no longer evident.