Dual-Loop Intra-Atrial Reentry in Humans

Dipen Shah, MD; Pierre Jais, MD; Atsushi Takahashi, MD; Meleze Hocini, MD; Jing Tian Peng, MD; Jacques Clementy, MD; Michel Haïssaguerre, MD

Background—Dual-loop atrial reentrant tachycardias have not been clinically described.

Methods and Results—Five patients (3 men, 2 women; mean age, 48±16 years) were studied 24±15 years after surgical closure of an ostium secundum atrial septal defect for drug-resistant atrial tachycardia. Complete tachycardia mapping was performed in the right atrium with multipolar catheters and a 3-dimensional electroanatomic mapping system (Biosense), followed by linear radiofrequency ablation of the narrowest part of each complete loop. Six tachycardias with a typical flutter morphology, a cycle length of 262±40 ms, and a superior f-wave axis (−77±11°) were mapped, 4 with a Biosense map including 106±32 points. Five figure-8 tachycardias had a counterclockwise loop around the tricuspid valve sharing a common anterior channel with a clockwise loop around the lateral atriotomy scar. One tachycardia was thought to have 2 counterclockwise loops around the same obstacles. Radiofrequency delivery in the cavotricuspid isthmus in each case transformed the tachycardia without any pause in a different morphology tachycardia with an inferior P-wave axis (50±42°) and nearly the same cycle length (272±39 ms) but with the periatriotomy loop alone. This arrhythmia required ablation of a second isthmus: between the lower end of the atriotomy and the inferior vena cava in 4 and the superior tricuspid annulus in 1. After a follow-up of 19±6 months, there were no recurrences.

Conclusions—Figure-8 double-loop tachycardias mimicking the ECG pattern of a common atrial flutter occur in some patients after a surgical atriotomy. Ablation of 1 loop produces a sudden transformation to a new reentrant tachycardia formed of the remaining loop that requires ablation at a second isthmus. (Circulation. 2000;101:631-639.)

Key Words: atrial flutter ■ catheter ablation ■ heart defects, congenital ■ heart septal defects ■ surgery

Typical right atrial (RA) flutter in humans exemplifies the paradigm of single-loop reentry,1 and knowledge of its circuit has allowed its elimination by interruption of conduction in a vulnerable “isthmus.”2–4 Although ventricular arrhythmias with a figure-8 activation pattern have been demonstrated,5–7 such an atrial arrhythmia has not been described clinically. In this report, we describe the complete circuit of intra-atrial figure-8 reentry in humans and its treatment by radiofrequency (RF) ablation at 2 isthmuses.

Methods

Between February 1996 and December 1997, 5 patients with a double-loop atrial reentry were investigated in our laboratory. The 3 men and 2 women had a mean age of 48±16 years (mean±SD), had undergone surgical closure of an ostium secundum atrial septal defect 24±15 years earlier, and had developed symptomatic tachycardia in the last 5±7 years. Two had 1 documented supraventricular tachycardia: 1 with 2 morphologies of atrial tachycardia and 1 with paroxysmal atrial fibrillation in addition to a single morphology of atrial tachycardia. They were selected from 15 consecutive patients studied during the same period for supraventricular tachycardia after surgical closure of an atrial septal defect; the remaining patients had single-loop circuits.

Electrophysiological Study and Ablation

Mapping and catheter ablation were performed with informed consent after 4 to 6 hours of fasting and after all antiarrhythmic drugs had been stopped for 48 hours. Femoral venous access was obtained to introduce a 6F quadripolar diagnostic catheter, a 7F quadripolar thermocouple equpped ablation catheter, and a duodecapolar Halo catheter (Cordis-Webster) into the RA. Bipolar electrograms were filtered between a band pass of 30 to 500 Hz and recorded at high gains of 0.1 mV/cm at a paper speed of 100 mm/s. A programmable stimulator (Cardiosimulator Ela Medical) with a 2-ms output pulse width and an amplitude 4 times the threshold was used.

Mapping Techniques

Sequential mapping of the cavotricuspid isthmus was performed during supraventricular tachycardia by recording activation at the ostium of the coronary sinus, at the lateral edge of the cavotricuspid isthmus (7 o’clock on the tricuspid annulus in the left anterior oblique view), and in its center (6 o’clock on the annulus) relative to the surface ECG onset of the flutter wave—in lead II, III, or aVF. Activation in the cavotricuspid isthmus was categorized as lateral to medial, medial to lateral, or convergent/colliding.9 A duodecapolar Halo catheter was placed in 2 patients with its most distal bipolar at 7 o’clock on the tricuspid annulus and its most proximal bipolar at 2 o’clock in the left anterior oblique view. Gentle torquing of the catheter shaft in either direction produced movement...
Summary of the Surface ECG and Intracardiac Mapping Features of the Double-Loop Tachycardias and Transformed Tachycardia

<table>
<thead>
<tr>
<th>Patient</th>
<th>Age, y</th>
<th>Sex</th>
<th>f-Wave Axis</th>
<th>CL, ms</th>
<th>Mapping</th>
<th>Loop 1</th>
<th>Loop 2</th>
<th>ECG Morphology</th>
<th>Mapping</th>
<th>CL, ms</th>
<th>Mapping (Isthmus)</th>
<th>Dual-Isthmus Ablation</th>
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<tbody>
<tr>
<td>1</td>
<td>63</td>
<td>F</td>
<td>-ve: II, III, aVF; -90°</td>
<td>250</td>
<td>L→M</td>
<td>141, Full CL</td>
<td>CCW-TV</td>
<td>CW-scar</td>
<td>Y</td>
<td>Dom+ve: II, III, aVF; +65°</td>
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<td>H: no change</td>
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<tr>
<td>2</td>
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<td>M</td>
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<td>225</td>
<td>L→M</td>
<td>CCW-TV</td>
<td>CW-scar</td>
<td>Y</td>
<td>Dom+ve: II, III, aVF; -30°</td>
<td>255</td>
<td>bIst/H: LRA full CL</td>
<td>Y</td>
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<tr>
<td>3</td>
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<td>M</td>
<td>-ve: II, III, aVF; 90°</td>
<td>335</td>
<td>L→M</td>
<td>64, Full CL</td>
<td>CCW-TV</td>
<td>CW-scar</td>
<td>Y</td>
<td>Dom+ve: II, III, aVF; +45°</td>
<td>350</td>
<td>3D: 89 pts full CL</td>
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<td>19</td>
<td>F</td>
<td>(1) -ve: II, III, aVF; 90°</td>
<td>(1) 270</td>
<td>L→M</td>
<td>111, Full CL</td>
<td>(1) CCW-TV</td>
<td>(1) CW-scar</td>
<td>Y</td>
<td>Dom+ve: II, III, aVF; +65°</td>
<td>270</td>
<td>3D: 93 pts full CL</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(2) -ve: II, III, aVF; 90°</td>
<td>(2) 230</td>
<td>L→M</td>
<td>CCW-TV</td>
<td>CCW-scar</td>
<td>Y</td>
<td>Dom+ve: II, III, aVF; +70°</td>
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<td>3D: 84 pts full CL</td>
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<tr>
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<td>-ve: II, III, aVF; -75°</td>
<td>260</td>
<td>L→M</td>
<td>111, Full CL</td>
<td>CCW-TV</td>
<td>CW-scar+SVC</td>
<td>Y</td>
<td>Dom+ve: II, III, aVF; +90°</td>
<td>260</td>
<td>3D: 83 pts full CL</td>
</tr>
</tbody>
</table>

CL indicates cycle length; I, isthmus; H, halo activation; 3D, 3D electroanatomic mapping with Biosense; -ve, negative; +ve, positive; L→M, lateral-to-medial cavotricuspid isthmus activation; CCW, counterclockwise; TV, around tricuspid annulus; CW, clockwise; Scar, around atriotomy; Dom, dominant; byst, convergent activation; LRA, lateral right atrium; pts, points; and +SVC, around SVC.

Definitions

Local block was defined by a conduction delay between contiguously located points of ≥30 ms produced by an activation detour around the block. The complete reentrant circuit was considered to be the spatially shortest route of unidirectional activation encompassing the full range of mapped activation times (>90% of the cycle length of the tachycardia) and returning to the site of earliest activation. Bystander fronts encompassed a significantly smaller range of activation timings and failed to return to the site of earliest activation. Double-loop reentry was considered to exist when 2 loops, each fulfilling the definition of a reentrant circuit, were simultaneously documented; ie, another front also demonstrated unidirectional activation spanning the full cycle length with terminal activation returning to the site of earliest activation. A figure-8 activation pattern was defined as a specific type of double-loop reentry involving 2 simultaneously coexisting loops rotating in opposite directions and sharing a common segment of unidirectional activation. Atriotomy scars were located and defined by contiguous low-voltage (<0.5 mV) double potentials commensurate with the surgical incision in the anterior right atrial free wall. Their position was confirmed by conventional or Biosense mapping in sinus rhythm.

The mean P- or f-wave axis of each tachycardia was calculated on the basis of the maximum amplitude in the limb leads relative to the intervening truly isoelectric baseline in case of P-wave tachycardias or the plateau in case of the typical sawtooth morphology fluctuations.

Ablation

RF energy was delivered in the cavotricuspid isthmus and from the inferior margin of the atriotomy scar down to the inferior vena cava (IVC). In 1 case, RF applications were delivered from the lower end of the scar as defined above to the nearest segment of the tricuspid annulus. The ablation sites were chosen on the basis of catheter stability as demonstrated fluoroscopically and on the electroanatomic and conventional mapping data. Sequential point-by-point ablation was performed with a catheter equipped with a 4-mm-tip electrode thermocouple connected to a Stockert-Cordis RF generator delivering a 550-kHz unmodulated sine wave output between the tip electrode and a 575-cm² back plate placed under the patient’s left shoulder. RF energy was delivered in the temperature-controlled mode (60°C to 70°C) for 60 to 90 seconds. Sedation with intravenous Midazolam was used as necessary. Successful ablation was defined as termination of the tachycardia by RF application and noninducibility of any organized atrial tachycardia. Isthmus block was verified during pacing in sinus rhythm and defined as a detour of activation around the cavotricuspid isthmus; similarly, complete block of the atriotomy incision line was defined by a detour of activation around the atriotomy and the contiguous great vessel (IVC or superior vena cava [SVC]) or annulus.

Results

Electrophysiological Study and Mapping of the Baseline Tachycardia

All patients were in spontaneous persistent flutter at the beginning of the study, an apparently typical atrial flutter with prominent negative deflections in leads II, III, aVF, and V₆; a
Figure 1. Figure-8 tachycardia with clockwise periatriotomy loop, coexisting counterclockwise pericardial loop, and transformation produced by cavotricuspid isthmus ablation. A, 3D electroanatomic map of baseline figure-8 tachycardia in RA (64 points) in 2 perspectives: left, modified left anterior oblique (LAO); right, modified right anterior oblique (RAO). More than 90% of cycle length of 330 ms is mapped within RA (note bar showing mapped activation time color range, 7 to 316 ms). Reference electrogram (Ref) is recorded from within coronary sinus. Selected electrograms at various points in RA are shown. Red and brown roundels represent double potentials. Activation proceeds in complete counterclockwise loop (thick black arrow from red to purple zone) around tricuspid valve viewed en face in LAO perspective and in similarly complete but clockwise loop around oblique line of block represented by double potentials in anterolateral RA wall. Cavotricuspid isthmus is activated from anterolateral to posteromedial (counterclockwise) as in typical counterclockwise atrial flutter. This circuit is schematically depicted in illustration on left side of B. B, RF energy was delivered in cavotricuspid isthmus, producing transformation of tachycardia from superior-axis P wave (left side of ECG tracing) to inferior-axis P wave with nearly same cycle length (350 ms) (right) as result of transformation of circuit shown in illustrations on left and right. Transformation (arrow) is instantaneous and without any intervening pause. C, 3D electroanatomic map of 89 points of transformed tachycardia in RA. As in A, activation proceeds in complete clockwise loop around atriotomy scar in anterolateral RA wall, but now activation around tricuspid valve is no longer unidirectional. Cavotricuspid isthmus is blocked, with collision of opposing wave fronts from 2 directions, both descending, confirming its bystander nature. This activation is schematically depicted on right of B. This tachycardia was successfully ablated by RF delivery at second isthmus between atriotomy scar and IVC. In A and C, each selected electrogram is accompanied by its activation time. Common amplitude and time scales for map electrograms are shown accompanying point with timing of 104 ms in A and 312 ms in C. Bottom scale bar indicates atrial size.
superiorly directed mean f-wave axis of \(-77\pm 11^\circ\); and a cycle length of \(262\pm 40\) ms.

Four RA 3D electroanatomic maps of \(106\pm 32\) points were obtained during different tachycardias in 4 patients (Table). In all cases, the cavotricuspid isthmus was activated unidirectionally from lateral to medial; the interatrial septum was activated caudocranially while activation coursed anteriorly to the SVC in the medial-to-lateral direction (counterclockwise) before descending down the free wall anterior to the atriotomy scar to return to the cavotricuspid isthmus. This descending front bifurcated into 2 toward the inferior end of the atriotomy scar. One continued into the cavotricuspid isthmus, whereas the other passed posteriorly through the narrow isthmus formed by the scar and the IVC, ascended upward along the posterior aspect of the RA free wall and the posterior RA. This clockwise circuit was completed by activation rejoining the descending corridor anterior to the atriotomy scar both around the SVC and between it and the superior aspect of the atriotomy scar (Figures 1 and 2). In 1 of these cases, a clockwise loop formed around the SVC and a contiguous atriotomy scar, along with a counterclockwise loop around the tricuspid annulus.

The 2 loops of activation spanning the full tachycardia cycle length were recorded in 1 case with conventional mapping only, with sequential isthmus mapping and with the Halo in position around the tricuspid annulus. Counterclockwise activation around the tricuspid annulus (including lateral-to-medial isthmus activation) combined with bifurcating ascending and descending activation on the RA free wall (Figure 2C). Counterclockwise activation around the tricuspid annulus alone could be documented in another patient with a Halo catheter, the second loop being demonstrated by only a 3D electroanatomic map.

**Tachycardia Transformation by Ablation**

RF applications were delivered in the cavotricuspid isthmus or at its lateral part. After a mean of \(7\pm 6\) RF applications, the flutter ECG changed abruptly into a dominant positive or completely positive deflection flutter in inferior leads II, III, aVF, and V6 with an inferiorly directed mean P-wave axis of \(50\pm 42^\circ\), a similar or identical cycle length (transformed cycle length, \(272\pm 39\) ms; change in cycle length, \(13\pm 11\) ms; range, 0 to 30 ms), and no intervening pause (Figures 1B and 2D). Less marked changes were seen in other leads: from negative to positive in aVR and aVL, isolectric to positive in I, and various morphological changes in chest leads.

One patient (patient 4) had a second tachycardia with a superior axis that was indistinguishable on the surface ECG.
from the presenting flutter except for its cycle length; sequential mapping of the isthmus also revealed lateral-to-medial activation. Ablation in the isthmus again produced a transformation to a different inferior-axis flutter (see below).

The transformed inferior-axis flutters were mapped with the 3D electroanatomic system in 4 cases (87±5 points), and 2 circuits were documented with a Halo catheter complemented by sequential mapping. Convergent bystander activation of the cavotricuspid isthmus by colliding wave fronts from 2 directions was demonstrated in all cases (Figure 1C). Five of the inferior-axis flutters were the result of a clockwise single-loop reentry circuit around the atriotomy scar. The 3D electroanatomic mapping revealed descending activation of the interatrial septum (Figure 1C). The sixth inferior-axis flutter in patient 4, however, was due to counterclockwise activation around the atriotomy scar.

Ablation of the Second Loop
Successful ablation of all the inferior-axis flutter morphologies was performed by delivering additional RF energy (12±15 applications) at a second isthmus in each patient—in 4 formed by the end of the atriotomy scar and the nearest great caval vein, the IVC—and in 1 patient between the lower end of the atriotomy scar and the superior tricuspid annulus (patient 5).
Procedural Outcome
During sinus rhythm, complete cavitricuspid isthmus block was verified in all patients, and block was achieved across the second isthmus between the lower end of the atriotomy scar and the IVC or the tricuspid annulus in 2 patients (Figure 2E). Despite multiple attempts, block could not be achieved in the isthmus between the lower end of the atriotomy scar and the superior tricuspid annulus in 1 patient. Block in the second isthmus was not verified in the other 2 patients. After a follow-up of 19±6 months (without antiarrhythmic drugs), there were no recurrences.
**Discussion**

This article describes the characteristics of dual-loop, figure-8 atrial reentry. All occurred in patients previously operated on for surgical closure of an ostium secundum atrial septal defect and required ablation of 2 isthmuses to be curative.

**Circuit Characteristics**

Double-loop figure-8 activation characteristically involved counterclockwise activation around the tricuspid valve and clockwise activation around the atriotomy, with activation from both loops coalescing into a common pathway anterior to it. In 1 case, both loops were counterclockwise, although other variations, including clockwise loops and >2 loops, are also possible.\(^\text{12}\)

The simultaneous coexistence of both loops was proved by comprehensive 3D mapping and transformation to a single-loop circuit with appropriately targeted RF application. Entrainment mapping was not systematically performed to avoid terminating or transforming the tachycardia or inducing atrial fibrillation (which could be considered a limitation). However, in view of the \(\leq 30\text{-ms}\) change in cycle length after transformation in 1 case, discordant postspacing intervals in the 2 loops may also be possible. Transection of 1 loop (peritricuspid) allowed unopposed atrial activation by the
other loop (periatriotomy) to be evident on the surface ECG. This novel mechanism of transformation of a reentrant tachycardia ECG may also be considered the gold standard test for a true figure-8 reentry circuit in which the remaining loop is capable of independent stability as opposed to a figure-8 activation pattern.5

Complete figure-8 circuits were first described by El Sherif et al,6 who mapped ventricular arrhythmias resulting from figure-8 activation patterns in the surviving epicardium 3 to 5 days after ligation of the left anterior descending artery in dogs. The 2 loops rotated around 2 separate arcs of functional block with a common channel of slow conduction. These lines of block were attributed to spatial inhomogeneities in repolarization and anisotropic myocardial properties. A cryothermal probe terminated the tachycardia only when applied to the common channel. Similar figure-8 ventricular circuit-based arcs of functional block have been mapped intraoperatively in patients with ischemic heart disease.6,7 Figure-8 atrial circuits have also been epicardially mapped in a canine sterile pericarditis model, again around lines of functional block.13

The figure-8 circuits (as well as the variant double-loop circuit) described in this article differ because activation evolved in the form of 2 loops around anatomic and fixed obstacles: the atriotomy scar in the free RA wall and the tricuspid valve annulus. This permitted the dual-loop reentrant circuit to function stably as a symbiotic arrhythmia and as a single-loop arrhythmia (resulting from the parent arrhythmia) by sectioning of the other loop. This tachycardia transformation could be considered a variant of Mines’ test for verifying the reentrant nature of each of the circuit’s constituent loops. The common channel between the 2 also did not behave like the slowest part of the circuit. The isthmuses themselves resulted from an atriotomy adjacent to multiple anatomical defects—the IVC and tricuspid valve—in the RA.

**ECC Recognition**

All patients presented with a typical-flutter ECG pattern with no features distinguishing this type of dual-loop figure-8 reentry circuit from typical counterclockwise isthmus-dependent flutter. All had undergone surgery for ostium secundum atrial septal defect closure representing 30% of a consecutive cohort (5 of 15). Such reentry might also probably be seen after a similar atriotomy for other forms of heart disease and in both atria. The small or nonexistent change in flutter cycle length after transection of the pericricuspud loop indicates the requirement of an appropriately long and freely hanging (not extending to the IVC or tricuspid valve annulus) atriotomy with or without a zone of slow conduction at its periphery to permit matching activation times around the atriotomy and tricuspid valve. After transection of 1 loop, the cycle length of the remaining loop (and therefore of the tachycardia) changed slightly in 4 of 6 instances, probably as a result of the loss of the modulating effect of the ablated loop. Despite the simultaneous coexistence of an additional circuit loop and posterior RA activation that was significantly different from that in typical flutter,10 the ECG was indistinguishable from that of typical flutter, indicating that simultaneous periatrotomy loop activation is not clearly evident on the surface ECG and that similarly posterior RA activation in typical flutter may not contribute to the surface ECG tracing. The role of the crista terminalis in these arrhythmias is unclear, although in each case the center of the RA free wall loop (the atriotomy) was in an anatomic position that was clearly distinct (lateral and anterior) from that expected of the crista terminalis. Additionally, activation in this region during tachycardia was parallel to the long axis of the crista terminalis, thus masking any marker double potentials. Mapping in sinus rhythm confirmed the position and fixed nature of the atriotomy line of block in 3 patients.

The double-loop mechanism was revealed on ECG only by transection of 1 loop. The ECG transformation was instantaneous and without an intervening pause, which might suggest termination followed by induction. The mapping of transformation of a superior-axis negative-deflection flutter (in inferior leads) to a positive-deflection flutter (inferior P-wave axis) with a periatrotomy reentry circuit indicates that the polarity change on the surface ECG is associated with altered septal activation from caudocranial to craniocaudal and possibly a similar change in left atrial activation. In all the above cases, ablation was begun in the cavotricuspid isthmus; however, if we had begun by ablating the IVC-atrotomy isthmus, in all likelihood no significant surface ECG changes would have occurred because the resulting change in atrial activation would be limited to only a part of the lateral and posterior RA, which appears to be silent on the ECG.

**Ablation**

The dual-loop reentry circuit required ablation at 2 distinct isthmuses. Although theoretically ablation of the common corridor between the atriotomy scar and the tricuspid annulus represents a more parsimonious approach, catheter stability in this region is a major problem. Moreover, ablation of this corridor would not be expected to be effective in the event of a single-loop typical-flutter circuit or a counterclockwise double-loop circuit; therefore, such an ablation strategy would require prior recognition of a figure-8 circuit by detailed intracardiac mapping.

**Conclusions**

A specific type of figure-8 reentry circuit involving simultaneously the atriotomy scar and the tricuspid valve can be encountered in post–atrial septal defect surgical closure patients with apparently typical atrial flutter. Ablation of the cavotricuspid isthmus transects the pericricuspud loop and leaves a single periatrotomy loop tachycardia, producing an instantaneous change in the ECG pattern, which requires ablation in a second isthmus.

**References**


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