Role of the Tricuspid Annulus and the Eustachian Valve/Ridge on Atrial Flutter
Relevance to Catheter Ablation of the Septal Isthmus and a New Technique for Rapid Identification of Ablation Success

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Abstract

Background Typical atrial flutter (AFL) results from right atrial reentry by propagation through an isthmus between the inferior vena cava (IVC) and tricuspid annulus (TA). We postulated that the eustachian valve and ridge (EVR) forms a line of conduction block between the IVC and coronary sinus (CS) ostium and forms a second isthmus (septal isthmus) between the TA and CS ostium.

Methods and Results Endocardial mapping in 30 patients with AFL demonstrated atrial activation around the TA in the counterclockwise direction (left anterior oblique projection). Double atrial potentials were recorded along the EVR in all patients during AFL. Pacing either side of the EVR during sinus rhythm also produced double potentials, which indicated fixed anatomic block across EVR. Entrainment pacing at the septal isthmus and multiple sites around the TA produced a Δ return interval ≤ 8 ms in 14 of 15 patients tested. Catheter ablation eliminated AFL in all patients by ablation of the septal isthmus in 26 patients and the posterior isthmus in 4. AFL recurred in 2 of 12 patients (mean follow-up, 33.9±16.3 months) in whom ablation success was defined by the inability to reinduce AFL, compared with none of 18 patients (mean follow-up, 10.3±8.3 months) in whom success required formation of a complete line of conduction block between the TA and the EVR, identified by CS pacing that produced atrial activation around the TA only in the counterclockwise direction and by pacing the posterior TA with only clockwise atrial activation.

Conclusions (1) The EVR forms a line of fixed conduction block between the IVC and the CS; (2) the EVR and the TA provide boundaries for the AFL reentrant circuit; and (3) verification of a complete line of block between the TA and the EVR is a more reliable criterion for long-term ablation success.

Key Words: atrial flutter • mapping • catheter ablation • radiofrequency

Introduction

Atrial flutter was described early in this century and was considered to be the result of a macroureentrant circuit in the right atrium in the vicinity of the venae cavae. In recent decades, this hypothesis was supported by mapping of activation in animal models of atrial flutter and typical atrial flutter in humans with sequential catheter recordings and with simultaneous multielectrode maps of atrial activation during surgery. The prevalent interpretation of the activation maps has been that the reentrant circuit contains a long segment that propagates anteriorly in the interatrial septum and another that propagates posteriorly along the lateral wall of the right atrium, but the specific course of the circuit in its anterior and posterior aspects has been unclear. A line of conduction block extending between the venae cavae has been thought to separate the septal and free wall segments. In recent years, it has been shown that the reentrant circuit courses between the inferior vena cava and the tricuspid annulus posteriorly and that this posterior isthmus is an opportune site to interrupt the circuit with a lesion induced by radiofrequency current.

We recently postulated the presence of a second line of conduction block extending between the inferior vena cava and the coronary sinus ostium that forces the reentrant impulse to propagate between the coronary sinus ostium and the tricuspid annulus and forms another, more narrow isthmus (septal isthmus) amenable to ablation. In this hypothesis, the reentrant atrial wavefront propagates around the tricuspid annulus, between the annulus and the inferior vena cava posteriorly (site A in Fig 1A), and arrives at the line of block between the coronary sinus ostium and the inferior vena cava (site B in Fig 1A). The impulse travels anteriorly only through the region between the coronary sinus ostium and the tricuspid annulus (site C in Fig 1A). Atrial activation then proceeds anteriorly along the tricuspid annulus (site D in Fig 1A) and simultaneously pivots around the coronary sinus ostium, back toward the inferior vena cava (site E in Fig 1A). Electrograms in the region of the line of block would be expected to exhibit two distinct atrial potentials separated by an isoelectric interval (double potentials). The first potential is generated by the arriving wavefront on the posterior side of the line of block (site B in Fig 1A), whereas the second potential is generated by the...
The study population consisted of 30 patients referred for catheter ablation of atrial flutter (Table 1). There were 19 men and 11 women, ranging in age from 20 to 75 years (mean, 50±16 years). Atrial flutter with typical flutter wave morphology (inverted sawtooth pattern in the inferior ECG leads) was the predominant clinical arrhythmia. Atrial flutter was chronic/incessant in 11 patients and paroxysmal in 19 of the 30 patients (63%). At least one episode of atrial fibrillation had been documented in 12 of the 30 patients (40%) and episodes of atrial tachycardia in 2 patients. A mean of 3.5±1.4 (range, 2 to 6) antiarrhythmic drugs had failed to prevent recurrences of atrial flutter. Palpitations and other symptoms that had been attributed to atrial flutter were present for a mean of 7±6.3 years. Atrial flutter produced syncope or presyncope in 13 patients. Structural heart disease was present in 23 of the 30 (77%) patients. Echocardiographic evidence of left atrial enlargement (>4 cm) and/or right atrial enlargement was present in 15 of the 30 (50%) patients. Seven of the 30 (23%) patients had previously undergone an unsuccessful attempt at catheter ablation of the atrial flutter at another institution. One of these patients (No. 7) underwent an atrioventricular nodal modification procedure (using the anterior approach) after failure to eliminate the atrial flutter.
Electrophysiological Study Protocol

Classes I and III antiarrhythmic drugs were withdrawn at least 5 days before study and aspirin (325 mg daily) was administered 1 day before the study. After providing written informed consent, each patient underwent electrophysiological study in the fasting state under heavy sedation with fentanyl (25 to 100 µg/h) and midazolam (1 to 4 mg/h). Oxygen saturation was monitored with a pulse oximeter, and expired carbon dioxide was monitored with a capnometer. Five multipolar electrode catheters (2-mm interelectrode spacing or orthogonal electrodes) were inserted percutaneously into the right subclavian vein and the right and left femoral veins. Three of the catheters were advanced to the right atrial appendage, His bundle region, and coronary sinus. A 7F deflectable catheter with 20 electrodes spaced in 2-7-2-mm intervals (Halo catheter, Cordis Webster) was positioned around the tricuspid annulus to record atrial activation close to the lateral and posterior tricuspid annulus (TA in Fig 3A). The remaining catheter was used for right atrial mapping (MAP in Fig 3A). One of these catheters (or an additional catheter) was positioned in the right ventricle during the ablation portion of the procedure.

In 18 of the 30 patients, the orthogonal coronary sinus catheter was advanced from the inferior vena cava to the proximal coronary sinus to obtain recordings along the eustachian valve/ridge between the inferior vena cava and the coronary sinus (IVC-CS). Entrainment pacing was performed during atrial flutter at a cycle length 15 to 25 ms shorter than the flutter cycle length. The sequence of atrial activation at all electrode recording sites of the multielectrode catheters was compared with the atrial activation sequence at these same sites during atrial flutter. The return interval was defined as (return interval) minus (flutter cycle length). The sequence of atrial activation at each electrode site was displayed at low gain (5 to 20 mV/cm). Close bipolar intracardiac electrograms (2-mm spacing or orthogonal electrodes) were recorded from each catheter with a filter bandwidth of 30 to 500 Hz and were displayed at low gain (5 to 20 mV/cm).

In patients with sinus rhythm at the onset of the procedure, atrial flutter was induced by programmed atrial stimulation with up to three extrastimuli and burst pacing at two atrial sites (right atrial appendage and posterior or posterolateral coronary sinus). If atrial flutter was not induced or was not sustained in the baseline state, isoproterenol (0.5 to 2 µg/min) was administered by continuous infusion and programmed atrial stimulation was repeated.

During atrial flutter, mapping of the right atrium and coronary sinus was performed to identify the atrial activation sequence along the tricuspid annulus, around the coronary sinus ostium, along the region between the coronary sinus ostium and the inferior vena cava (including the eustachian valve/ridge), and in the proximal coronary sinus. Entrainment pacing was performed in 15 of the 30 patients at (1) the posteroseptal right atrium between the coronary sinus ostium and the tricuspid annulus (site C in Fig 1A), (2) anterior and posterior to the line of double potentials extending along the eustachian valve/ridge between the coronary sinus ostium and the inferior vena cava (sites E and B in Fig 1B), and (3) at several free wall sites around the tricuspid annulus. Entrainment pacing was performed during atrial flutter at a cycle length 15 to 25 ms shorter than the flutter cycle length. The sequence of atrial activation at all electrode recording sites during entrainment pacing was compared with the atrial activation sequence at these same sites during atrial flutter. The return interval was defined as the interval from the last pacing stimulus to the return atrial potential, which was recorded at the pacing site. When amplifier saturation prevented the recording of the return atrial potential at the pacing site, the timing of the return atrial potential was estimated from the timing of return atrial potentials recorded close to the pacing site. The Δ return interval was defined as (return interval) minus (flutter cycle length). The Δ return interval was used as an estimation of the distance of the entrainment pacing site from the reentrant circuit.

In 15 of the 19 patients who were in sinus rhythm before ablation, atrial pacing (at long cycle lengths) was used to determine whether the line of conduction block along the eustachian valve/ridge was present in the absence of atrial flutter (fixed anatomic block versus functional block during atrial flutter). Two deflectable electrode catheters were positioned just anterior and posterior to the eustachian valve/ridge (Fig 4A). Atrial pacing (cycle length >500 ms) was performed individually from the anterior and posterior catheters, and the timing of atrial activation at the opposite catheter was compared with the timing of atrial activation at the coronary sinus ostium. Later atrial activation at the opposite catheter than at the coronary sinus ostium (or the region between the tricuspid annulus and the coronary sinus ostium) would suggest the presence of fixed anatomic conduction block at the eustachian valve/ridge with propagation of the paced atrial wavefront around the coronary sinus ostium or around the anterior portion of the eustachian ridge (Fig 5A). Earlier atrial activation at the catheter opposite to that at the coronary sinus ostium would indicate the presence of conduction across the eustachian valve/ridge and suggest that the block along the eustachian valve/ridge during atrial flutter is functional.

Table 1. Patient Characteristics

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Figure 3. Radiographs in the right anterior oblique projection (A) and left anterior oblique projection (B) show the positions of the multielectrode catheters in the right atrial appendage (RAA), His bundle region (HB), around the tricuspid annulus (TA), along the eustachian valve/ridge between the inferior vena cava and the coronary sinus (IVC-CS), and the mapping catheter (MAP) positioned at the septal isthmus. Arrows around the TA catheter identify the locations of bipolar electrode pairs. Electrograms are shown in Figs 10 and 11.

Figure 4. Radiograph in the right anterior oblique projection shows the two electrode catheters used for atrial pacing on the anterior (Ant) and posterior (Post) sides of the eustachian valve/ridge, which lies parallel to the IVC-CS catheter. The electrograms are shown in Fig 13. Same patient as in Figs 3, 10, and 11.
Catheter Ablation

The primary approach for radiofrequency catheter ablation of the atrial flutter was to create a line of atrial conduction block between the tricuspid annulus and the coronary sinus ostium (Line SI in Fig 2C, Fig 6A, and Fig 7A and 7B). If the eustachian valve/ridge provides a line of block between the coronary sinus ostium and inferior vena cava, that ablation should create an arc of conduction block (tricuspid annulus–coronary sinus ostium–inferior vena cava) and eliminate the atrial flutter (Fig 6A).

The ablation catheter was inserted through one of the right femoral venous sheaths, and the tip electrode was positioned against the posteroseptal right atrium, close to the tricuspid annulus at the level of the posterior margin of the coronary sinus ostium. During atrial flutter, the distal bipolar electrogram at this site recorded a single atrial potential that was closer in timing to the first potential of the double potentials recorded just behind the coronary sinus ostium. This electrogram pattern was thought to represent activation in the proximal portion of the septal isthmus between the tricuspid annulus and the coronary sinus ostium. Sites that recorded atrial activation closer in timing to the second potential of the double potentials were avoided because this activation pattern could represent activation at a site distal to the exit of the septal isthmus. The tip electrode was then advanced slightly toward the right ventricle (at the level of the posterior margin of the coronary sinus ostium).
ostium) until the distal bipolar electrogram recorded a low-amplitude atrial potential with a large, sharp ventricular potential, indicating a location close to the tricuspid annulus (Fig 7A). Radiofrequency current (550 to 650 kHz) then was delivered to the tip electrode at 45 to 60 V when using a 7F/4-mm tip electrode (Cordis Webster) in 20 patients and 50 to 70 V when using an 8F/8-mm tip electrode (EP Technologies) in 10 patients (Table 3). Two adhesive electrosurgical dispersive pads (both positioned over the left posterior chest) were used for the return electrode. The ablation electrode was withdrawn toward the posteroaopal margin of the coronary sinus ostium in 2- to 3-mm increments every 15 to 20 seconds while radiofrequency current was continuously applied (Fig 6A and Fig 7A and 7B). When the electrode entered the posteroaopal edge of the coronary sinus ostium (Fig 7B), the voltage was lowered to 45 to 50 V, and slight forward pressure (toward the tricuspid annulus) was applied to the catheter to enhance current delivery to the tissue between the coronary sinus ostium and the tricuspid annulus. When possible, radiofrequency current was delivered between the tricuspid annulus and the coronary sinus ostium as a single, continuous application. However, the application of radiofrequency current was terminated immediately in the event of an impedance rise (≥10 Ω). In that event, two or more radiofrequency applications were required to produce the contiguous lesion. Voltage output was guided by impedance monitoring (avoiding more than 5- to 10-Ω decreases in impedance) to reduce the incidence of impedance rise.35

**Table 3. Ablation Results**

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<th>Time to Abduction</th>
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If atrial flutter persisted after one or more radiofrequency applications between the tricuspid annulus and the coronary sinus ostium, radiofrequency current was applied along the posterior margin of the coronary sinus ostium and between the posterior margin of the ostium and the eustachian ridge (Figs 6B and 7C). If atrial flutter still persisted, radiofrequency current was applied along a line between the posterior or posterior paraseptal tricuspid annulus and the inferior vena cava or the eustachian ridge (Line PI in Fig 2C and Fig 6C).

This sequential approach, beginning with a lesion between the tricuspid annulus and the coronary sinus ostium, was used in 27 of the 30 patients. In the remaining 3 patients (Nos. 7, 19, and 24), radiofrequency current was only delivered between the posterior tricuspid annulus and the inferior vena cava or the eustachian valve/ridge (Fig 6C). In 2 of these patients (Nos. 7 and 19) it was thought that elimination of the posterior input to the AV node (slow AV nodal pathway) by ablation of the septal isthmus might produce AV block. One of these patients (No. 7) had previously undergone an AV nodal modification procedure using the anterior approach, which might have eliminated the anterior inputs to the AV node (fast AV nodal pathway). The other patient (No. 19) had an A-H interval of 205 ms during sinus rhythm (and no retrograde AV nodal conduction) after a myomectomy for hypertrophic obstructive cardiomyopathy, which might have indicated the absence of conduction over the fast AV nodal pathway (anterior inputs to the AV node). The third patient (No. 24) had a persistent left superior vena cava inserting into the great cardiac vein. This was associated with a giant coronary sinus ostium that displaced the eustachian ridge to approximately 4 cm from the tricuspid annulus. In this patient, we believed that a continuous lesion could be created more reliably through the posterior isthmus than through the septal isthmus.

**Criteria for Successful Ablation and Termination of the Ablation Procedure**

In 12 patients, ablation success was defined by (1) the termination of atrial flutter during an application of radiofrequency current due to conduction block within the reentrant circuit at the ablation site and (2) the inability to reinduce atrial flutter for a period of at least 30 minutes by programmed stimulation of the right and left atria (from the posterior or posterolateral coronary sinus), including extensive burst pacing (noninduction criteria). Isoproterenol was used in the postablation testing in patients who required isoproterenol for induction of atrial flutter before ablation at a dose exceeding the preablation dose.

In 18 patients, ablation success was defined by (1) the noninduction criteria and (2) the demonstration of a line of bidirectional conduction block between the tricuspid annulus and the eustachian valve/ridge (line of block criteria). We verified complete conduction block between the tricuspid annulus and the eustachian ridge by pacing the right atrium adjacent to the posterior tricuspid annulus (posterior to the ablation line) and noting that atrial activation propagates around the tricuspid annulus in the clockwise direction (as viewed in the left anterior oblique projection), with late atrial activation at the anterior septum (His bundle electrogram) by ablation of the septal isthmus, including extensive burst pacing (noninduction criteria). Isoproterenol was used in the postablation testing in patients who required isoproterenol for induction of atrial flutter before ablation at a dose exceeding the preablation dose.

**Figure 8. Schematics illustrate the pacing technique used to verify a complete arc of conduction block after ablation of the septal isthmus (gray lines in B and D). A, Right atrial pacing adjacent to the posterior tricuspid annulus before ablation results in atrial activation around the tricuspid annulus in both the clockwise and counterclockwise directions with relatively early atrial activation recorded in the His bundle and proximal coronary sinus electrograms. B, After ablation of the septal isthmus, producing a complete arc of conduction block from the tricuspid annulus to the CS ostium, eustachian ridge, and IVC. Right atrial pacing adjacent to the posterior tricuspid annulus results in atrial activation around the tricuspid annulus only in the clockwise direction with late atrial activation recorded in the HB electrogram and even later activation recorded from the proximal CS. C, Left atrial pacing from the proximal CS before ablation results in right atrial activation from the septum in both the clockwise and counterclockwise directions. D, After ablation, left atrial pacing from the proximal CS produces right atrial activation only in the counterclockwise direction with the latest atrial activation recorded immediately posterior to the ablation line. Abbreviations as in previous figures. S indicates atrial pacing site.**

**Postablation Management**

Patients were electrocardiographically monitored until hospital discharge on the second day after ablation. A transesophageal echocardiogram was obtained on the day after ablation to exclude a thrombus at the ablation sites, pericardial effusion, and tricuspid valve injury. The patients received aspirin (325 mg daily) for 6 weeks. No patient received antiarrhythmic drug therapy after ablation until recurrence of atrial flutter or atrial fibrillation. Patients were followed by the investigators...
Statistical Analysis

Data are listed as mean±SD. The significance of the difference between the Δ return intervals at the various entrainment pacing sites was assessed by ANOVA, with Scheffe’s method for pairwise comparisons. A χ² test was used to determine the significance of the difference in atrial flutter recurrence between the two criteria for successful ablation and the significance of the difference in the clinical occurrence of atrial fibrillation after ablation between the presence or absence of structural heart disease, atrial enlargement, and previously documented atrial fibrillation. The number of applications of radiofrequency current was compared between the patients with or without previous ablation failure and the presence or absence of an episode of atrial fibrillation after ablation using a two-tailed, unpaired t test. A value of P<.05 was considered statistically significant.

Results

Atrial flutter was present at the onset of the electrophysiological study in 11 of the 30 patients. The ECG exhibited the pattern of typical atrial flutter with a negative flutter wave in the inferior leads in 10 of these 11 patients. Reverse typical atrial flutter (defined later) with a positive flutter wave in the inferior leads was present in the remaining patient (No. 20), who had had clinical episodes of both typical and reverse typical flutter. In the other 19 patients, typical atrial flutter was induced by extrastimuli or burst atrial pacing from the right atrial appendage and/or the coronary sinus (Fig 9A). Isoproterenol (1 to 2 µg/min) was required for sustained atrial flutter in 6 patients (Table 2). In 4 patients (Nos. 22 and 25 through 27), sustained typical atrial flutter could not be maintained because of spontaneous termination or recurrent spontaneous degeneration to atrial fibrillation. Episodes of reverse typical atrial flutter also were induced in 7 patients before ablation. Episodes of reverse typical atrial flutter were induced in 3 additional patients after elimination of typical atrial flutter by ablation. Therefore, typical atrial flutter was studied in 29 patients and reverse typical atrial flutter in 10 patients. The atrial cycle length during typical atrial flutter was 242±52 ms (Table 2). Sustained atrial flutter (≥60 seconds) was induced by programmed atrial stimulation in 10 patients before ablation and 2 patients after ablation of atrial flutter (Table 3).

Figure 9. Induction of atrial flutter by burst atrial pacing from the coronary sinus. Tracings from the top are ECG lead II and bipolar electrograms recorded from the right atrial appendage (RAA), His bundle region (HB), lateral (TA₉,₁₀) to posterior tricuspid annulus (TA₇), mapping catheter with distal pair of electrodes positioned at the anterior end of the septal isthmus (MAPₐ), and proximal pair of electrodes positioned just behind the coronary sinus ostium overlying the eustachian ridge (MAPₚ), and the posterior (CSₗ) to posterolateral coronary sinus (CSₗ₋₋ₚ) A. During sinus rhythm, three extrastimuli (S₂, S₃, S₄) were delivered to the posterolateral coronary sinus. S₃ and S₄ activated the posterior left atrium (CS electrograms) and the right atrial anterior to the septal isthmus (MAPₚ and HB electrograms), but conduction block within the septal isthmus resulted in selective activation of the right atrium around the tricuspid annulus in the counterclockwise direction as viewed in the left anterior oblique projection, with early atrial activation recorded in the HB electrogram (A) followed by atrial activation in the TA electrograms from the lateral (TA₇) to posterior (TA₉) initiating typical atrial flutter. B. Electrograms during typical atrial flutter demonstrate atrial activation around the TA in the counterclockwise direction with secondary left atrial activation recorded progressively from CSₗ₋₋ₚ to CSₗ electrograms. Note the double potentials recorded in MAPₚ electrograms recorded just behind the CS ostium.

Table 2. Electrophysiological Characteristics of Atrial Flutter

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Endocardial Mapping

Recordings along the tricuspid annulus during typical atrial flutter showed atrial activation propagating around the tricuspid annulus in the counterclockwise direction as viewed in the left anterior oblique projection (anteriorly along the septum and posteriorly along the free wall) in all 29 patients (Figs 9 and 10). Left atrial activation, recorded from the proximal coronary sinus, occurred soon after the timing of atrial activation in the septal isthmus (Fig 9B). Left atrial activation was recorded at progressively later times at more distal sites in the coronary sinus, consistent with activation of the left atrium in the counterclockwise direction as viewed in the left anterior oblique projection. During reverse typical atrial flutter, atrial activation propagated around the tricuspid annulus in the clockwise direction as viewed in the left anterior oblique projection (Fig 11).

Figure 10. Double potentials recorded along the eustachian valve/ridge during typical atrial flutter. Catheter positions are shown in Fig 3. A. During typical atrial flutter, counterclockwise atrial activation around the tricuspid annulus is manifested by atrial activation in the HB electrograms followed by activation in the TA electrograms from lateral (TA₉) to posterior (TA₈) and then by activation at the septal isthmus (MAPₚ). The IVC-CS electrograms, recorded using the eustachian valve/ridge, show double potentials, which indicate a line of conduction block. The first potentials in the IVC-CS₁ to IVC-CS₇ electrograms (bold downward arrows) were recorded before the timing of atrial activation in the septal isthmus (MAPₚ and vertical dashed line) and resulted from activation along the posterior/inferior side of the eustachian valve/ridge. The second potential (upward arrows) was recorded after atrial activation in the septal isthmus and resulted from atrial activation on the anterior/superior side of the eustachian valve/ridge. The interval between the two potentials is shortest at the anterior end of the line of conduction block (IVC-CS₇) and largest at the posterior end close to the inferior vena cava (IVC-CS₇), consistent with pivoting of the
Electrograms recorded from the septal isthmus, between the coronary sinus ostium and the tricuspid annulus, exhibited wide atrial potentials that often had multiple components but not discrete double potentials separated by isoelectrical interval (MAP electrogram in Fig 12). Conduction block in the septal isthmus was responsible for the spontaneous termination of typical atrial flutter in 11 patients, which suggests that the septal isthmus may have a low safety factor for impulse propagation. Conduction block at this site in the anterior-to-posterior direction was responsible for the induction of typical atrial flutter by burst pacing from the coronary sinus in 6 patients (Fig 9A).

**Double Potentials**

Distinct double potentials separated by an isoelectrical interval (consistent with conduction block) were recorded along the eustachian valve/ridge from the anterior/superior margin of the coronary sinus ostium to the inferior vena cava in all 29 patients during typical atrial flutter (Figs 1, 3, and 10). The first of the two potentials was large and sharp and the second potential was small and rounded (distant) when the recording electrodes were positioned posterior/inferior to the line of equal amplitude double potentials, indicating a location proximal to (below) the line of block (MAP-A electrogram in Fig 12). The second of the two potentials was large and sharp and the first potential was small and distant when the recording catheter was positioned anterior/superior or distal to (above) the line of equal amplitude potentials (MAP-B electrogram in Fig 12), which suggests a location distal to (above) the line of block (MAP-C electrogram in Fig 12). Atrial activation in the septal isthmus between the tricuspid annulus and the coronary sinus ostium (site C in Fig 1) followed the timing of the first potential of the double potentials and preceded the second potential of the double potentials recorded along the eustachian valve/ridge (MAP electrogram in Fig 10). The timing of the second potential became progressively later from the coronary sinus end to the inferior vena cava end of the eustachian valve/ridge. The greatest interval between the two potentials (91±17 ms, Table 2) was consistently recorded near the inferior vena cava end of the eustachian valve/ridge. The second potential of the two potentials was usually recorded after atrial activation in the His bundle electrogram, which suggests that the second potential may represent activation outside of the reentrant circuit.

Double potentials also were recorded along the eustachian valve/ridge during reverse typical atrial flutter. The order of the two potentials was reversed (compared with typical flutter), with the first potential resulting from atrial activation anterior to (above) the eustachian valve/ridge and the second potential resulting from activation posterior to (below) the eustachian valve/ridge (Fig 11).

Double potentials were not recorded along the eustachian valve/ridge during sinus rhythm (Fig 10B). However, double potentials were consistently elicited by right atrial pacing at long cycle lengths just anterior or posterior to the eustachian valve/ridge, with activation occurring in the septal isthmus before activation of the opposite side of the eustachian valve/ridge (Figs 4 and 13).

**Figure 11.** Relationship of double potentials between typical and reverse typical atrial flutter. Patient and catheter positions are the same as in Figs 3 and 10. A, During reverse typical atrial flutter, the atrial impulse propagated around the tricuspid annulus in the clockwise direction, reflected by atrial activation at the septal isthmus (MAPd) followed by atrial activation at the posterior tricuspid annulus (TA) and lateral tricuspid annulus (TAb), opposite to the pattern recorded during typical atrial flutter (B). Double potentials, separated by an isoelectrical interval, were recorded along the eustachian valve/ridge (IVC-CS to IVC-CS) during reverse typical atrial flutter. The first potential resulted from atrial activation anterior to the eustachian valve/ridge (Above EVR) and the second potential resulted from activation posterior to the eustachian valve/ridge (Below EVR). Note the order of the two potentials is opposite to the order in typical atrial flutter (B). Abbreviations as in previous figures.

**Figure 12.** Characteristics of the double potentials recorded along the eustachian valve/ridge. The bottom three tracings are composed electrograms recorded at three sites shown schematically on the right (A, B, and C). MAP-B was recorded on the eustachian ridge. The two potentials of the double potential are approximately equal in amplitude. MAP-A was recorded on the posterior/inferior side of the eustachian ridge and exhibited a large, sharp first potential and a small, rounded second potential (representing far field activation on the anterior/superior side of the eustachian ridge). MAP-C was recorded anterior/superior to the eustachian ridge. The second potential is large and sharp, whereas the first potential is small and rounded (far field activation from the posterior/inferior side of the eustachian ridge). Abbreviations as in previous figures.

**Figure 13.** Evidence obtained by atrial pacing for fixed conduction block across the eustachian valve/ridge. Catheter positions are shown in Fig 4. The anterior (Ant) and posterior (Post) catheters are positioned just anterior and posterior to the eustachian valve/ridge, respectively. A, During atrial pacing from the distal pair of electrodes on the Ant catheter at a cycle length of 600 ms, the proximal pair of electrodes on the Post catheter (Postx, located close to the eustachian valve/ridge) recorded two distinct potentials separated by an isoelectric interval. The first potential resulted from atrial activation anterior to the eustachian valve/ridge and the second (delayed) potential resulted from atrial activation posterior to the eustachian valve/ridge. The distal pair of electrodes on the Post catheter (Posty) were located further from the eustachian valve/ridge and recorded only a single delayed potential. The IVC-CSd electrogram is recorded at the anterior margin of the coronary sinus ostium and shows atrial activation midway in timing between the anterior and posterior potentials recorded along the eustachian valve/ridge. B, During atrial pacing from the distal pair of electrodes on the Post catheter at a cycle length of 600 ms, the distal pair of electrodes...
Entrainment Pacing

Entrainment pacing (cycle length, 15 to 25 ms shorter than the flutter cycle length) at the septal isthmus, between the tricuspid annulus and the coronary sinus ostium, produced an atrial activation sequence that was identical to the flutter in all recorded electrograms (concealed entrainment) in each of the 15 patients tested. The Δ return interval (return interval minus flutter cycle length) at this pacing site was 0 to 15 ms (mean, 4.2±4.3 ms) and 58 ms in 14 of the 15 patients (Fig 14A and Table 2).

Figure 14. Entrainment pacing from the septal isthmus and anterior and posterior to the eustachian valve/ridge during typical atrial flutter. A, MAP electrograms were recorded from the septal isthmus between the tricuspid annulus and the tricuspid annulus proximal to the pacing site (TA

Entrainment pacing just posterior to the eustachian valve/ridge, which corresponds to site B in Fig 1, produced an atrial activation sequence identical to the flutter but with a Δ return interval of 8 to 50 ms (mean, 30±12 ms) and 15 ms in 14 of the 15 patients (Fig 14B and Table 2). Entrainment pacing just anterior to the eustachian valve/ridge (site E in Fig 1) produced a Δ return interval of 15 to 60 ms (mean, 37±13 ms) (Fig 14C and Table 2).

Entrainment pacing from sites along the right atrial free wall adjacent to the tricuspid annulus produced some alternation of the atrial activation sequence close to the pacing site and alteration of the P wave. However, the Δ return interval was 58 ms in 14 of the 15 patients (Fig 15 and Table 2). In the remaining patient (No. 23), the Δ return interval was 15 ms at all sites tested around the tricuspid annulus and at the septal isthmus.

Figure 15. Entrainment pacing at two sites along the free wall tricuspid annulus. Catheter positions are shown in C. A shows the last 4 complexes of entrainment pacing from the TA
to TA
electrode on the Halo catheter located at the septal margin of the coronary sinus ostium. Note that the return interval was 275 ms, identical to the atrial flutter cycle length (Δ return interval=0 ms). B shows the last 4 complexes of entrainment pacing from the TA
electrode on the Halo catheter located at the lateral tricuspid annulus. Entrainment pacing at this site also resulted in a return interval of 275 ms (Δ return interval=0 ms), indicating that these two sites around the tricuspid annulus were remote from the reentrant circuit. Note that the A-A interval was 275 ms at all of the sites along the tricuspid annulus distal to the pacing site (TA

to TA
electrograms) and the A-A interval was equal to the pacing cycle length (260 ms) at sites along the tricuspid annulus proximal to the pacing site (HB, TA
and TA
electrograms). The IVC-CS

electrograms recorded atrial activation on the anterior side of the eustachian valve/ridge (second potential of the double potentials), while the IVC-CS

electrograms recorded atrial activation in the proximal coronary sinus. The MAP
electrogram was recorded at the septal isthmus and exhibits a potential midway between the double potentials recorded on the IVC-CS
electrogram, while the MAP
electrogram was recorded behind the coronary sinus ostium and exhibits a potential close in timing to the second potential of the double potentials in the IVC-CS
electrogram. C, Radiograph in the left anterior oblique projection showing the location of the catheter electrodes for A and B. Arrows indicate the location of 10 close bipolar electrodes on the Halo catheter positioned around the tricuspid annulus. Abbreviations as in previous figures.
Catheter Ablation

In 27 of the 30 patients, ablation was initiated with applications of radiofrequency current delivered along a line between the tricuspid annulus and the posteroapical margin of the coronary sinus ostium, as illustrated in Fig 6A (approach A). Ablation only in this region eliminated atrial flutter in 14 of the 27 patients with 1 to 16 (median, 2) applications of radiofrequency current (column “A” in Table 3). Extending the ablation line to the eustachian ridge (including the posterior margin of the coronary sinus ostium), as illustrated in Fig 6B (approach A and B), eliminated the atrial flutter in 12 additional patients (column “A and B” in Table 3). In 2 of these 12 patients (Nos. 9 and 10), typical atrial flutter was eliminated by ablation approach A, but reverse typical atrial flutter then was induced by programmed atrial stimulation. The reverse typical atrial flutter was eliminated by extending the ablation line to the eustachian ridge. Therefore, ablation using approach A or approach A and B eliminated typical and reverse typical atrial flutter in 26 of the 27 patients with 1 to 21 (median, 3; mean, 5.8±5.5) applications of radiofrequency current. The one remaining patient (No. 16) required additional ablation between the tricuspid annulus and the inferior vena cava to eliminate atrial flutter (column “A, B, and C” in Table 3). This patient had a large coronary sinus ostium that was located more anteriorly than usual, and a His bundle potential was recorded at the anterior margin of the coronary sinus ostium. The unusual anatomy and our concern about the possibility of producing heart block significantly limited attempts to create a line of block between the tricuspid annulus and the coronary sinus ostium.

In 3 patients with either a high risk of AV block (patients 7 and 19) or a giant coronary sinus ostium caused by a persistent left superior vena cava or a large coronary sinus ostium (equivocal to a site anterior to the ablation line). During right atrial pacing adjacent to the posterior tricuspid annulus, a contiguous line of block eliminated early anterior and leftward propagation of the atrial impulse, manifested by propagation of the atrial impulse around the tricuspid annulus in the clockwise direction (as viewed in the left atrial oblique projection with late activation at the anterior septum (His bundle electrogram) and early later activation of the posterior left atrium recorded from the proximal coronary sinus (Fig 8A and 8B and Fig 17A, 17B, and 17E). A more striking shift in the pattern of atrial activation around the tricuspid annulus was observed during coronary sinus pacing. Before ablation, coronary sinus pacing resulted in activation of the right atrium in both the anterior and posterior directions, producing activation around the tricuspid annulus in both the counterclockwise and clockwise directions (Figs 8C and 17C). After completion of the line of conduction block, the right atrium was activated only in the anterior direction, which resulted in activation around the tricuspid annulus in only the counterclockwise direction (Figs 8D and 17D). The activation time at the posteriorparaseptal right atrium (anterior to the ablation line) during coronary sinus pacing shifted from the earliest right atrial activation time before ablation to the latest time after ablation (Fig 17C and 17D).

The number of applications of radiofrequency current required to eliminate atrial flutter was not significantly different for 7 patients with previous ablation failure (mean, 6.7±6.2; Tables 1 and 3).

Criteria for Ablation Success

In 12 patients, ablation was considered successful and the procedure was terminated when an application of radiofrequency current eliminated the atrial flutter (Fig 16) and neither typical nor reverse typical atrial flutter was induced by programmed atrial stimulation (noninduction criteria, Table 3). In the remaining 18 patients, ablation was not considered successful until the noninduction criteria were met and a line of complete bidirectional conduction block was produced between the posteroseptal tricuspid annulus and the eustachian valve/ridge (line of block criteria, Table 3). The completion of the line of conduction block was verified by right atrial pacing adjacent to the posterior paraseptal tricuspid annulus (posterior to the ablation line) and by pacing the left atrium from the posterior coronary sinus (equivalent to a site anterior to the ablation line). During right atrial pacing adjacent to the posterior tricuspid annulus, a contiguous line of block eliminated early anterior and leftward propagation of the atrial impulse, manifested by propagation of the atrial impulse around the tricuspid annulus in the clockwise direction (as viewed in the left atrial oblique projection with late activation at the anterior septum (His bundle electrogram) and even later activation of the posterior left atrium recorded from the proximal coronary sinus (Fig 8A and 8B and Fig 17A, 17B, and 17E). A more striking shift in the pattern of atrial activation around the tricuspid annulus was observed during coronary sinus pacing. Before ablation, coronary sinus pacing resulted in activation of the right atrium in both the anterior and posterior directions, producing activation around the tricuspid annulus in both the counterclockwise and clockwise directions (Figs 8C and 17C). After completion of the line of conduction block, the right atrium was activated only in the anterior direction, which resulted in activation around the tricuspid annulus in only the counterclockwise direction (Figs 8D and 17D). The activation time at the posteriorparaseptal right atrium (anterior to the ablation line) during coronary sinus pacing shifted from the earliest right atrial activation time before ablation to the latest time after ablation (Fig 17C and 17D).

Figure 16. Radiofrequency catheter ablation of typical atrial flutter using approach A. A. Tracings at the bottom are the current and voltage output of the radiofrequency generator. This figure shows the second application of radiofrequency current. The first application of radiofrequency current was delivered while the ablation catheter was slowly moved from the tricuspid annulus to the midpoint between the tricuspid annulus and the posteroapical margin of the coronary sinus ostium. The second application of radiofrequency current, shown in this figure, was delivered while the ablation electrode was moved from the end point of the first radiofrequency application to the posteroapical margin of the coronary sinus ostium at 51 V (30 W). B. Termination of atrial flutter 18 seconds after the onset of the second application of radiofrequency current, when the ablation electrode was maneuvered into the posteroapical margin of the coronary sinus ostium. Atrial flutter was terminated with conduction block in the septal isthmus, manifested by the absence of atrial activation after activation at the posterior tricuspid annulus (TA). Abbreviations as in previous figures.

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Figure 17. Electrograms illustrate the line of block criteria for ablation success. Catheter positions are shown in E. A. Before ablation, right atrial pacing adjacent to the posterior tricuspid annulus (TA, bipolar electrode) resulted in atrial activation around the tricuspid annulus in the clockwise direction (shorter upward arrow indicating activation from TA to TA) and in the counterclockwise direction (represented by the downward arrow indicating propagation to the MAP electrogram recorded at the septal isthmus, followed by the long upward arrow labeled “Septal” and indicating propagation to the HB electrogram recording site at the anterior septum). The proximal coronary sinus (IVC-CS) to IVC-CS electrograms) was activated relatively early after the pacing stimulus. B. Ablation of the septal isthmus, pacing adjacent to the posterior paraseptal tricuspid annulus (TA, bipolar electrode) resulted in atrial activation propagating around the tricuspid annulus only in the clockwise direction, with a marked delay in the timing of atrial activation in the HB electrogram (relative to the RAA and TA electrograms) and even later activation recorded in the proximal coronary sinus (IVC-CS electrograms). Note the double potentials in the MAP electrogram recorded at the septal isthmus, indicating atrial activation on both sides of the line of conduction block produced by ablation. C. Pacing the left atrium from the posterior coronary sinus before ablation resulted in right atrial activation around the tricuspid annulus in both the clockwise direction (short upward arrow with serial atrial activation in TA to TA electrograms) and the counterclockwise direction (long upward arrow) with early atrial activation recorded in the HB electrogram following atrial activation at the anterior (TA) and anterolateral tricuspid annulus (TA). D. After ablation of the septal isthmus, left atrial pacing via the posterior coronary sinus resulted in atrial activation propagating around the tricuspid annulus only in the counterclockwise direction, with early atrial activation in the HB electrogram.
The presence of a complete line of conduction block was examined in 1 of the 3 patients in whom reverse typical atrial flutter was induced after elimination of typical atrial flutter by ablation (patient 9 in Table 3). Conduction across the ablation region was still present, manifested by early activation of the posterior right atrium adjacent to the tricuspid annulus during coronary sinus pacing. Extending the ablation line to the eustachian ridge was associated with the development of a complete line of conduction block and elimination of reverse typical atrial flutter.

In 15 of the 18 patients in whom line of block criteria were used to define ablation success, a line of conduction block was present as soon as the inducibility of typical and reverse typical atrial flutter was eliminated. In the remaining 3 patients (Nos. 28, 29, and 30), atrial flutter was terminated by the third to eighth application of radiofrequency current and neither forms of atrial flutter could be induced, but some degree of conduction across the ablation region was still present during pacing from the posterior right atrium (adjacent to the tricuspid annulus) or coronary sinus. In these 3 patients, the defect in the line of conduction block was found by pacing from the coronary sinus and mapping just posterior to the ablation line to locate an early atrial potential (Fig 18A and 18B). Ablation at that site was followed by a shift in the atrial activation sequence along the posterior tricuspid annulus from the clockwise direction to the counterclockwise direction as viewed in the left anterior oblique projection (Fig 18B, 18D, and 18E). Importantly, neither typical nor reverse typical atrial flutter was induced after the completion of the line of conduction block in any of the 18 patients.

In 1 of the 12 patients (No. 7) in whom the noninduction criteria were used to define ablation success, conduction across the ablation line was still present after the fifth application of radiofrequency current despite noninducibility of atrial flutter. No further applications of radiofrequency current were delivered.

In 4 patients, ablation could not be performed during atrial flutter because of either frequent spontaneous termination of atrial flutter (patients 25 and 27) or frequent spontaneous conversion of atrial flutter to atrial fibrillation (patients 22 and 26). Ablation was performed during left atrial pacing from the posterior coronary sinus until a line of conduction block was evident by the abrupt delay in the timing of atrial activation at the postero septal tricuspid annulus (posterior to the eustachian valve/ridge) with a shift in the atrial activation sequence along the lateral and posterior tricuspid annulus from the clockwise direction to the counterclockwise direction as viewed in the left anterior oblique projection (Fig 18E). Complete bidirectional block between the tricuspid annulus and the eustachian ridge was confirmed by pacing the right atrium adjacent to the posterior tricuspid annulus (posterior to the ablation site) and noting a marked delay in the timing of atrial activation at the antero septal tricuspid annulus (His bundle region) and posteroseptal left atrium recorded from the coronary sinus (Fig 17B).

**Follow-up**

The 30 patients have been followed for 3 to 60 months (mean, 19.7±16.7 months). Atrial flutter recurred at 1 and 5 months in 2 (17%) of the 12 patients (Nos. 6 and 7) in whom the noninduction criteria were used to define ablation success (mean follow-up of 33.9±16.3 months, Table 3). This includes the patient (No. 7) in whom complete conduction block was shown to be absent at the end of the procedure despite noninducibility of atrial flutter. The presence or absence of a line of conduction block was not determined in the other patient (No. 6) who had a recurrence of atrial flutter. In contrast, atrial flutter has not recurred in any of the 18 patients (P<.05) in whom ablation was continued until the line of block criteria were fulfilled (mean follow-up of 10.3±8.3 months, Table 3).

At least one episode of atrial fibrillation occurred 2 days to 2 months after ablation in 8 (27%) of the 30 patients (Table 3). Compared with the 22 patients without atrial fibrillation after ablation, these 8 patients had a significantly greater incidence of structural heart disease (8 of 8 versus 14 of 22, P<.05), left or right atrial...
between the eustachian ridge and the coronary sinus ostium may be a reflection of since extension of the ablation line to the eustachian ridge was required to complete the arc of conduction block. The block criteria were used, since ablation just along the septal isthmus (approach The preexisting line of conduction block along the eustachian valve/ridge appeared to extend to the coronary sinus ostium around the tricuspid annulus in the counterclockwise direction (Fig 8C and 8D along the eustachian valve/ridge, combined with preexisting conduction around the tricuspid annulus in the clockwise direction as viewed in the left anterior oblique projection (Fig 8A and 8B coronary sinus resulted in early activation of the right atrium anterior and superior to the eustachian valve/ridge, whereas the second potential was large and sharp in recordings immediately posterior and inferior to the eustachian valve/ridge and was small and rounded (distant appearing) in recordings anterior and superior to the eustachian valve/ridge, whereas the second potential was large and sharp in recordings immediately anterior and superior to the eustachian valve and was small and rounded in recordings posterior and inferior to the eustachian valve/ridge (Fig 12•). The interval between the double potentials was bridged uninterrupted by recordings along the septal isthmus (from posterior to anterior) and then around the anterior margin of the coronary sinus ostium (in the counterclockwise direction as viewed in the right anterior oblique projection; Fig 10•). This is consistent with arrival of the reentrant wavefront at the posterior/inferior side of the line of conduction block along the eustachian valve/ridge (first potential) followed by pivoting of the wavefront around the anterior margin of the coronary sinus ostium to activate the atrium on the anterior/superior side of the eustachian valve/ridge (second potential), as illustrated schematically in Fig 1•. The observation that the interval between the two potentials of the double potentials is greatest in recordings close to the inferior vena cava (posterior end of the eustachian valve/ridge) supports the concept that the impulse propagates around the anterior end of the eustachian valve/ridge. Importantly, recordings from the septal isthmus (between the tricuspid annulus and the coronary sinus ostium) did not exhibit distinct double potentials (MAP2 electrogram in Fig 9• and MAP electrogram in Fig 10•) because the line of conduction block extends behind (superior to) the coronary sinus ostium, which is relatively far from the recording electrodes (Fig 1•). The line of conduction block along the eustachian valve/ridge also was present before induction of atrial flutter. During atrial pacing at rates just slightly faster than the sinus rate on either side of the eustachian valve/ridge, double potentials were recorded along the eustachian valve/ridge with late atrial activation on the opposite side (Figs 4, 5, and 13••••), indicating the presence of fixed anatomic block as opposed to functional block during atrial flutter. The finding of fixed block might be expected because the eustachian ridge contains primarily connective tissue, including the tendon of Todaro, with variable components of muscle. A line of fixed anatomic block also might be expected in patients without atrial flutter, but this remains to be examined.

Distinct double potentials were not recorded during sinus rhythm (Figs 10B and 13C••••). The absence of double potentials indicates that the right atrium on both sides of the eustachian valve/ridge is activated nearly simultaneously during sinus rhythm. This may result from activation by a single wavefront propagating relatively parallel to the eustachian valve/ridge27 but could result also from the simultaneous arrival of multiple wavefronts. The response to ablation of the septal isthmus provides additional evidence of preexisting, fixed anatomic conduction block along the eustachian valve/ridge. After completion of the ablation line between the tricuspid annulus and the coronary sinus ostium or the eustachian ridge, pacing the right atrium posterior to the ablation line failed to activate the atrium on the other side of the ablation line and the posterosetal left atrium until after the paced atrial impulse propagated around the tricuspid annulus in the clockwise direction as viewed in the left anterior oblique projection (Fig 8A and 8B••••). Similarly, pacing the posterior left atrium from the coronary sinus resulted in early activation of the right atrium anterior to the ablation line and anterior/superior to the eustachian valve/ridge, but conduction block along the eustachian valve/ridge prevented activation of the right atrium immediately posterior to the ablation line until the atrial impulse propagated completely around the tricuspid annulus in the counterclockwise direction (Fig 8C and 8D••••). Therefore, the ablation line between the tricuspid annulus and the eustachian valve/ridge, combined with preexisting conduction block along the eustachian valve/ridge, form a complete arc of conduction block extending from the tricuspid annulus to the coronary sinus ostium and to the inferior vena cava

The preexisting line of conduction block along the eustachian valve/ridge appeared to extend to the coronary sinus ostium in 8 of the 16 patients in whom the line of block criteria were used, since ablation just along the septal isthmus (approach A) produced the complete arc of conduction block in these patients (Table 3•). Conduction between the eustachian ridge and the coronary sinus ostium may have been present in the remaining half of the 16 patients (dashed arrow in Fig 6B••••), since extension of the ablation line to the eustachian ridge was required to complete the arc of conduction block. The presence or absence of conduction block between the eustachian ridge and the coronary sinus ostium may be a reflection of the variability in the anatomic relationship between the connective tissue of the eustachian ridge and the thebesian valve of the coronary sinus ostium, as illustrated in Fig 2•.

Reentrant Circuit in Atrial Flutter

Complications

There were no acute or late complications of the ablation procedure. Transesophageal echocardiography performed after ablation in all 30 patients showed no intracardiac thrombus, pericardial effusion, or injury to the tricuspid valve.

Discussion

This study examined the hypothesis that the eustachian valve/ridge forms a line of conduction block in typical atrial flutter between the inferior vena cava and the coronary sinus ostium that forces the reentrant impulse emerging from the posterior isthmus (between the tricuspid annulus and the inferior vena cava21) to propagate through the septal isthmus, between the tricuspid annulus and the coronary sinus ostium. The results of this study strongly support this hypothesis, including the recording of double potentials along the eustachian valve/ridge during typical and reverse typical atrial flutter, the response to pacing on either side of the eustachian valve/ridge, and the creation of an arc of conduction block extending from the tricuspid annulus to the coronary sinus ostium and the inferior vena cava by catheter ablation of the septal isthmus, eliminating atrial flutter.

Conduction Block Along the Eustachian Valve/Ridge

Waldo and other investigators19 20 24 25 26 27 28 29 have shown that a line of conduction block in the atrium is manifested by double potentials separated by an isoelectric interval. The first potential results from the arrival of the atrial impulse on one side of the line of block, whereas the second potential results from the later atrial activation on the other side of the line of block. In this study, double potentials were recorded during typical and reverse typical atrial flutter along a line extending from the region behind (and superior to) the coronary sinus ostium to the inferior vena cava in all 30 patients (Figs 9 through 12••••). Using intracardiac echocardiography, Olgin et al36 recently showed that the line of double potentials corresponded to the anatomic location of the eustachian valve/ridge (Fig 2•). The first potential of the double potentials during typical atrial flutter was large and sharp in electrograms recorded immediately posterior and inferior to the eustachian valve/ridge and was small and rounded (distant appearing) in recordings anterior and superior to the eustachian valve/ridge, whereas the second potential was large and sharp in recordings immediately anterior and superior to the eustachian valve and was small and rounded in recordings posterior and inferior to the eustachian valve/ridge (Fig 12•). The interval between the double potentials was bridged uninterrupted by recordings along the septal isthmus (from posterior to anterior) and then around the anterior margin of the coronary sinus ostium (in the counterclockwise direction as viewed in the right anterior oblique projection; Fig 10•). This is consistent with arrival of the reentrant wavefront at the posterior/inferior side of the line of conduction block along the eustachian valve/ridge (first potential) followed by pivoting of the wavefront around the anterior margin of the coronary sinus ostium to activate the atrium on the anterior/superior side of the eustachian valve/ridge (second potential), as illustrated schematically in Fig 1•. The observation that the interval between the two potentials of the double potentials is greatest in recordings close to the inferior vena cava (posterior end of the eustachian valve/ridge) supports the concept that the impulse propagates around the anterior end of the eustachian valve/ridge. Importantly, recordings from the septal isthmus (between the tricuspid annulus and the coronary sinus ostium) did not exhibit distinct double potentials (MAP2 electrogram in Fig 9• and MAP electrogram in Fig 10•) because the line of conduction block extends behind (superior to) the coronary sinus ostium, which is relatively far from the recording electrodes (Fig 1•).
Entrainment pacing is a powerful tool to determine whether a region of myocardium is located within the reentrant circuit of a tachycardia. Spontaneous conversion from the isthmus by placing a line of block criteria was used for ablation success (Table 3). In the 2 patients who had recurrence of atrial flutter after seemingly successful ablation by the noninduction criteria, the line of block criteria were not fulfilled (ie, conduction was present across the ablation line) in one patient and not examined in the other. These observations strongly suggest that the line of block criteria are superior to the noninduction criteria to predict long-term ablation success of atrial flutter. The completion of the ablation-induced line of conduction block between the tricuspid annulus and the eustachian valve/ridge is quickly and easily identified by pacing the posterior or posterior paraseptal right atrium adjacent to the tricuspid annulus just posterior to the ablation line and by pacing the posterior left atrium from the coronary sinus. This technique also can be used with ablation of the posterior isthmus by placing the catheter electrodes posterior or lateral to the ablation line (Table 3). Identification of the line of block by coronary sinus pacing has been described recently in an animal model of atrial flutter and in a preliminary clinical report.

An important advantage of the line of block criteria is the ability to perform ablation without requiring atrial flutter during the application of radiofrequency current. In 4 of the 30 (13%) patients, atrial flutter could not be maintained for ablation because of either frequent spontaneous termination of atrial flutter (2 patients) or frequent spontaneous conversion from atrial flutter to atrial fibrillation (2 patients). We performed ablation during left atrial pacing from the proximal coronary sinus in these patients.
patients using the shift in atrial activation along the posterior tricuspid annulus from the clockwise direction to the counterclockwise direction to identify ablation success. Ablation during coronary sinus pacing also was used to complete the line of conduction block in the 3 patients with persistence of conduction across the ablation line after elimination of the inducibility of atrial flutter (patients 28 to 30, Table 3). Mapping immediately posterior to the ablation line during coronary sinus pacing was used to identify the residual area of conduction through the ablation line (Fig 18). The ability to recognize ablation success without requiring the induction of atrial flutter either before or after ablation may significantly shorten total procedure time and fluoroscopy time as well as increase the long-term ablation success rate for typical and reverse typical atrial flutter.

Occurrence of Atrial Fibrillation After Ablation of Atrial Flutter
Previous studies of catheter ablation of atrial flutter have shown a high occurrence of atrial fibrillation after ablation. In this study, at least one episode of atrial fibrillation occurred during follow-up in 8 of the 30 (27%) patients (Table 3). Compared with the 22 patients without subsequent atrial fibrillation, these 8 patients had a higher incidence of major structural heart disease, right or left atrial enlargement, and previously documented episodes of atrial fibrillation. They also received a greater number of applications of radiofrequency current. The combination of right or left atrial enlargement and a history of atrial fibrillation was a strong predictor of subsequent occurrence of atrial fibrillation (6 of the 8 patients with this combination compared with 2 of the 22 patients without these two risk factors, \( P<0.01 \)). Ablation of atrial flutter still may be helpful in this group of patients since atrial fibrillation and/or the ventricular response rate may be tolerated better by the patient or better controlled pharmacologically. It is unclear whether the larger number of applications of radiofrequency current in the patients with subsequent atrial fibrillation (median, 11 versus 3) is causally related to the atrial fibrillation or simply a reflection of the increased difficulty in performing ablation in this group of patients with greater structural heart disease and dilated atria.

Conclusions
The eustachian valve/ridge forms a line of conduction block extending from the inferior vena cava to the coronary sinus ostium, which, combined with the tricuspid annulus, forms a protected channel within the reentrant circuit of typical and reverse typical atrial flutter. The posterior end of this channel forms the posterior isthmus (between the inferior vena cava and the tricuspid annulus) and its anterior end forms the septal isthmus (between the coronary sinus ostium and the tricuspid annulus). Ablation of the septal isthmus was found to be highly successful in eliminating typical and reverse typical atrial flutter, although extension of the ablation line to the eustachian ridge was required in half of the patients. This study describes a new technique for defining ablation success by confirming that the ablation line has produced a complete arc of conduction block extending from the tricuspid annulus to the coronary sinus ostium and the inferior vena cava. This new criteria for ablation success may reduce the recurrence of atrial flutter after seemingly successful ablation and also allow successful ablation without requiring the presence of atrial flutter at the time of ablation.

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Footnotes

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Characterization of Low Right Atrial Isthmus as the Slow Conduction Zone and Pharmacological Target in Typical Atrial Flutter