Importance of Atrial Flutter Isthmus in Postoperative Intra-Atrial Reentrant Tachycardia

David P. Chan, MD; George F. Van Hare, MD; Judith A. Mackall, MD
Mark D. Carlson, MD; Albert L. Waldo, MD

Background—In survivors of congenital heart surgery, intra-atrial reentrant tachycardia (IART) often develops. Previous reports have emphasized the atriotomy scar as the central barrier around which a reentrant circuit may rotate but have not systematically evaluated the atrial flutter isthmus in such patients. We sought to determine the role of the atrial flutter isthmus in supporting IART in a group of postoperative patients with congenital heart disease.

Methods and Results—Nineteen postoperative patients with IART underwent electrophysiological studies with entrainment mapping of the atrial flutter isthmus for determining postpacing intervals. Radiofrequency ablation was performed at the identified isthmus in an effort to create a complete line of block. Twenty-one IARTs were identified in 19 patients, with a mean tachycardia cycle length of 293±73 ms. The atrial flutter isthmus was part of the circuit in 15 of 21 (71.4%). In the remaining 6 of 21, the ablation target zone was at sites near atrial incisions or suture lines. Ablation was successful in 19 of 21 (90.4%) IARTs and in 14 of 15 (93.3%) cases at the atrial flutter isthmus.

Conclusions—In most of our postoperative patients, the atrial flutter isthmus was part of the reentrant circuit. The fact that the atrial flutter isthmus is vulnerable to ablation suggests that whenever IART occurs late after repair of a congenital heart defect, the atrial flutter isthmus should be evaluated. These data support the theory that some form of conduction block between the vena cava is essential for the establishment of a stable substrate for the atrial flutter reentrant circuit. (Circulation. 2000;102:1283-1289.)

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

In survivors of congenital heart surgery, intra-atrial reentrant tachycardia (IART) often develops. This tachyarrhythmia, which has also been called atrial flutter, can be difficult to manage and represents a significant cause for morbidity and mortality in postoperative patients with congenital heart disease.1 There has been much interest in using radiofrequency ablation (RFA) to cure IART because it is often difficult to control with antiarrhythmic drug therapy4 and may be poorly tolerated hemodynamically. Previous reports have emphasized the atriotomy scar as the central barrier around which a reentrant circuit could rotate.5–7

The reentrant circuit in typical and reverse typical atrial flutter is now well understood.8–14 The critical isthmus that supports the reentrant circuit in typical and reverse typical atrial flutter is between the tricuspid annulus, the coronary sinus os, and the Eustachian ridge adjacent to the inferior vena cava. In typical atrial flutter, reentry proceeds in a counterclockwise fashion when the tricuspid annulus is viewed in the left anterior oblique view, whereas in reverse typical atrial flutter, it proceeds in a clockwise fashion.15 This isthmus has been referred to as the atrial flutter isthmus, and targeting this isthmus with radiofrequency energy has been associated with a high success rate in ablating typical and reverse typical atrial flutter.10,11,14,16–18

Previous reports have indicated that successful RFA can be achieved in postoperative patients with congenital heart disease who have IART.5–7,19 Ablation therapy has focused on extending a line of block from the surgical incision to an appropriate boundary, such as the atrioventricular (AV) groove, the inferior vena cava, or the superior vena cava. For example, Kalman et al7 placed ablative lesions between an atriotomy scar or suture lines and another boundary, usually the AV groove, in all but 1 patient. However, we hypothesized, on the basis of a series of studies of atrial flutter in animal models, that the right atriotomy in such patients could serve as the needed posterior boundary of the IART reentrant circuit such that the resulting IART could use the typical and reverse typical atrial flutter isthmus as part of the reentrant circuit.20 If this is correct, the atrial flutter isthmus could be targeted for ablation of the clinical tachyarrhythmia, just as it is in typical and reverse typical atrial flutter. Previous reports have not systematically evaluated the atrial flutter isthmus in such patients. We therefore sought first to determine the role of the atrial flutter isthmus in supporting IART in a group of
postoperative patients with congenital heart disease in whom entrainment mapping techniques were used during electrophysiological study. Second, we sought to determine whether the atrial flutter isthmus could be a potential target site for successful RFA to cure the IART when it has been determined to be part of the reentrant circuit in this patient population.

Methods

Patient Selection
From 1994 to 1998, there were 35 postoperative patients with congenital heart disease who were examined at University Hospitals of Cleveland with findings of IART. Of these, 19 underwent electrophysiological studies that included careful entrainment mapping of the atrial flutter isthmus as part of evaluation for RFA therapy. This latter group of patients comprises our cohort for the present retrospective study. The procedures followed were in accordance with institutional guidelines, and patients or their parents or guardians gave informed consent for the procedures.

Electrophysiological Study
Each patient underwent standard electrophysiological testing in a laboratory with either biplane fluoroscopy or single-plane fluoroscopy that allowed rapid movement of the fluoroscopy arm from right anterior to left anterior oblique projections. Electrode catheters were placed to record from the coronary sinus, the bundle of His, and the right ventricle. In addition, when possible, a 20-pole halo electrode catheter was placed in the right atrium such that it encircled the tricuspid valve, with the distal pair of electrodes near the os of the coronary sinus. All intracardiac electrograms were recorded (bandpass 50 to 300 Hz) simultaneously with surface ECG leads V1, V2, II, III, and aVF (bandpass 0.05 to 300 Hz) on a commercially available computer amplifier system (Quinton Electrophysiology) in a digital format. After measurements of intervals and assessment of AV node function, IART was initiated with standard programmed stimulation techniques. Entrainment mapping was performed, as previously described, during IART for assessment of postpacing intervals (PPI). This was performed by both pacing and recording from the distal electrode pair of a mapping catheter that was initially placed at the atrial flutter isthmus. Pacing was performed at cycle lengths 20 to 30 ms shorter than the tachycardia cycle length. The PPI and the atrial flutter isthmus block through the atrial flutter isthmus was also used as a criterion for success. This was judged both in the clockwise direction, observing a change in the order of atrial activation of the lateral atrial wall during proximal coronary sinus pacing, as well as the counterclockwise direction, observing a change in the order of atrial activation at the coronary sinus versus the site where the His bundle was recorded. A change in P-wave morphology with low lateral right atrial pacing from inverted to upright in lead aVF was also used as a criterion of counterclockwise isthmus block.

Results

Patients
The mean age of our cohort of 19 patients at the time of the electrophysiological study was 22.8±12.9 years (Table 1). Ten of the patients were male. In most cases, the clinical tachycardia had developed at a remote time from the congenital heart surgical repair (mean time from surgery to ablation, 16.9 years; range, 2 to 37 years).

In our cohort of 19 patients, 21 distinct IARTs were identified (Table 2). The mean tachycardia cycle length was 293±73 ms. At the electrophysiological study, 10 of the 21 tachycardias were either incessant or developed spontaneously at the time of catheter manipulation. Using entrainment mapping techniques, a target isthmus was identified in each tachycardia. The atrial flutter isthmus was found to be part of the circuit by entrainment criteria in 15 (71.4%) of the tachycardias and therefore was targeted for ablation. In the remaining 6 tachycardias, the target zone for ablation of the reentrant circuit was localized to sites near atrial incisions and/or suture lines rather than the atrial flutter isthmus. Only 2 of the tachycardias with the classic atrial flutter circuit circulated in a clockwise direction (as in reverse typical atrial flutter) by visualization of the tricuspid valve as a clock face in the left anterior oblique (Figures 1 and 2). In 1 of these patients, both clockwise and counterclockwise rotation were observed at different times. The PPI-TCL interval was 2.6±3.9 ms when pacing was performed at the chosen target isthmus. Initial success of ablation was achieved in 19 of the 21 (90.4%) IARTs. When the atrial flutter isthmus was identified as the target isthmus, successful ablation was achieved in 14 of 15 (93.3%) of cases. The success rate of RFA at other sites was 5 of 6 (83.3%) IARTs. At last follow-up, 7 of the 19 successfully ablated tachycardias had recurred. It is notable that only 4 of 14 (28.7%) ablated tachycardias involving the atrial flutter isthmus recurred, whereas 3 of the 5 ablated tachycardias not involving the atrial flutter isthmus recurred (60%). It is also notable that of the 6 typical or reverse typical atrial flutters for which bidirectional isthmus block could be demonstrated, only 1 recurred, whereas of the 2 flutters for which bidirectional block could not be demonstrated, both recurred (Table 2). Five patients had attempted repeat ablation that was successful in 4 and unsuccessful in 1. No complications were noted in association with either the electrophysiological study or the ablation procedures.

Discussion

IART in long-term survivors of surgical repair of congenital heart disease is an important clinical problem. Ablation therapy has proven to be effective in managing this particularly difficult problem in patients who have had relatively simple atrial surgery as well as those with Mustard and Senning procedures for transposition but has had a lower long-term success rate with patients who have undergone the Fontan procedure. Previous reports have concentrated on the use of ablative techniques to create block in the isthmus between the atriotomy incision and the AV groove in an attempt to eliminate the IART reentrant circuit. The
The present report has demonstrated that despite the presence of an atriotomy scar, the atrial flutter isthmus is a part of the reentrant circuit in many patients with a variety of types of congenital heart disease anatomy and can be targeted for ablation with a good rate of success. Alternatively, when the atrial flutter isthmus was not part of the reentrant circuit and other areas of the right atrium were targeted for ablation, the results of ablation were not as good. We suggest that this improved result relates to the well-defined atrial anatomy and the relative ease of localizing the band of tissue of interest at the atrial flutter isthmus. This is in comparison to the somewhat variable locations of the atriotomy scar and suture lines among patients. Thus, it may be technically more difficult to establish a line of block at other atrial sites, especially sites that include pectinate muscles. Furthermore, the techniques for documenting successful creation of a complete line of block are well developed in classic (typical and reverse typical) atrial flutter and involve the observation of the pattern of right atrial lateral wall activation during coronary sinus pacing, P-wave morphology during lateral wall pacing, and order of coronary sinus os versus low septal right atrial activation during lateral wall activation.17 The adoption of these criteria for proof of bidirectional block of the atrial flutter isthmus has been responsible for a dramatic improvement in long-term success rate for ablation of classic atrial flutter, and this point is borne out in our results, in which the demonstration of bidirectional block was predictive of long-term success. Such methods and criteria are as yet undeveloped in IART that does not involve the atrial flutter isthmus.

Value of Entrainment Mapping

The concept of entrainment24-25 has been adapted to mapping studies of various tachyarrhythmias, including IARTs.6,7,26 It is a particularly powerful technique in identifying components of the reentrant circuit, including a target isthmus for ablation. It should be noted that patients with IART often have much slower TCLs than those seen in patients with typical atrial flutter and usually lack the classic sawtooth atrial flutter waves on the surface ECG (Figure 1). Prior studies of postoperative atrial arrhythmias have never carefully assessed the tricuspid valve–Eustachian ridge isthmus in an organized, careful, and prospective fashion to determine whether it is in or out of the circuit. Having done this in this study, we have found that a surprisingly large number of patients who might otherwise have been classified as having incisional reentry in fact have IART involving the typical atrial flutter isthmus. Despite the fact that the typical appearance of atrial flutter was lacking in many of these patients, our series demonstrates that patients who are considered to have IART may still be approached in the same way for ablation as those with typical and reverse typical atrial flutter, provided that the atrial flutter isthmus is demonstrated to be part of the circuit by entrainment mapping.

### TABLE 1. Patient Characteristics

<table>
<thead>
<tr>
<th>Patient</th>
<th>Age at First Ablation, y</th>
<th>Congenital Cardiac Lesion</th>
<th>Surgical Procedure(s)</th>
<th>Years Since Surgery at Time of Ablation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10.7</td>
<td>Single RV, asplenia</td>
<td>Fontan atrioventricular connection</td>
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<tr>
<td>2</td>
<td>26.4</td>
<td>Secundum ASD, unroofed coronary sinus</td>
<td>Closure</td>
<td>21</td>
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<tr>
<td>3</td>
<td>14.7</td>
<td>Taussig-Bing anomaly</td>
<td>Mustard</td>
<td>12</td>
</tr>
<tr>
<td>4</td>
<td>14.4</td>
<td>D-TGA</td>
<td>Mustard</td>
<td>13</td>
</tr>
<tr>
<td>5</td>
<td>17.1</td>
<td>Primum and secundum ASD</td>
<td>Closure</td>
<td>16</td>
</tr>
<tr>
<td>6</td>
<td>17.1</td>
<td>D-TGA</td>
<td>Mustard</td>
<td>15</td>
</tr>
<tr>
<td>7</td>
<td>14.4</td>
<td>Tetralogy of Fallot</td>
<td>Complete repair via atriotomy</td>
<td>10</td>
</tr>
<tr>
<td>8</td>
<td>3.5</td>
<td>Secundum ASD</td>
<td>Closure</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>3.3</td>
<td>TAPVC</td>
<td>Complete repair via atriotomy</td>
<td>3</td>
</tr>
<tr>
<td>10</td>
<td>48.9</td>
<td>TOF and ASD</td>
<td>ASD closure</td>
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<tr>
<td>11</td>
<td>14.3</td>
<td>D-TGA</td>
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<td>13</td>
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<tr>
<td>12</td>
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<td>Aortic and mitral stenosis, small LV</td>
<td>Mitral valve replacement</td>
<td>18</td>
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<tr>
<td>13</td>
<td>29.9</td>
<td>Aortic valvular stenosis</td>
<td>Open valvuloplasty</td>
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<tr>
<td>14</td>
<td>27.7</td>
<td>Tetralogy of Fallot</td>
<td>Complete repair</td>
<td>20</td>
</tr>
<tr>
<td>15</td>
<td>31.5</td>
<td>AV canal</td>
<td>Complete repair</td>
<td>24</td>
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<tr>
<td>16</td>
<td>44.3</td>
<td>WPW</td>
<td>Surgical ablation via atriotomy</td>
<td>12</td>
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<tr>
<td>17</td>
<td>33.7</td>
<td>Tetralogy of Fallot</td>
<td>Complete repair via atriotomy and ventriculotomy</td>
<td>27</td>
</tr>
<tr>
<td>18</td>
<td>43.4</td>
<td>ASD</td>
<td>Closure</td>
<td>25</td>
</tr>
<tr>
<td>19</td>
<td>17.2</td>
<td>ASD and VSD</td>
<td>Closure of both defects</td>
<td>13</td>
</tr>
</tbody>
</table>

RV indicates right ventricle; ASD, atrial septal defect; D-TGA, D-transposition of the great arteries; TAPVC, total anomalous pulmonary venous connection; TOF, tetralogy of Fallot; LV, left ventricle; WPW, Wolff-Parkinson-White syndrome; and VSD, ventricular septal defect.
Why Does Late Postoperative Atrial Flutter Develop?

There is a relatively high incidence of IART among patients who are survivors of congenital heart surgery. 1 Atrial flutter as a primary arrhythmia is rare in children without structural heart disease but is seen relatively more frequently in adults without structural heart disease. It is now understood that for atrial flutter to occur, a stable line of block between the vena cavae must be present or must develop.20 Olgin et al 16 have proposed that in patients with typical or reverse typical atrial flutter, a line of block along the crista terminalis forms the posterior barrier for the atrial flutter circuit, and both Nakagawa et al10 and Kalman et al 11 have demonstrated that the tricuspid annulus forms the anterior barrier. Clearly, not all adults are prone to atrial flutter, and this suggests that block in the region of the crista terminalis is likely related to tissue abnormalities associated with atrial dilation, aging, or other factors. We suggest that the presence of 1 or more atriotomy scars or suture lines in young patients who have undergone surgical repair of a congenital heart lesion may serve to provide the posterior barrier needed to support a stable reentrant circuit. Indeed, as summarized recently,20 this is consistent with the findings in several canine models of atrial flutter, including those of Frame et al.27 In these models, a line of block between the superior vena cava and inferior vena cava has been demonstrated to be necessary to support sustained atrial flutter. Further mapping studies are needed in patients with tachycardia involving the atrial flutter isthmus to better delineate the remainder of the tachycardia circuit.

Implications for Nomenclature

These findings have implications for the nomenclature in use for describing atrial macroreentrant tachycardias in patients who have had atriotomies. The term “incisional reentry” was coined by Kalman et al7 and was used to describe a reentrant atrial tachycardia in patients in whom the reentrant circuit traveled around an atriotomy and in which an isthmus existed between the atriotomy and the AV groove (ie, between 2 anatomic barriers). Our data suggest that there are 2 groups of patients that may be described: those whose tachycardia involves the atrial flutter isthmus and those whose tachycardia circuit is distant from this isthmus. In the second group, the evidence for involvement of an atrial incision is fairly good, whereas in the first group, involvement of the
atrial incision is currently speculative. We favor continued use of the term “incisional reentry” to apply only to those tachycardias in which the atrial flutter isthmus has been shown by entrainment mapping to not be a part of the circuit. We suggest the use of the term “postoperative atrial flutter” for those tachycardias that involve the atrial flutter isthmus in postoperative patients. Finally, the term “intra-atrial reentrant tachycardia” probably should be used to refer to both types, particularly those not yet differentiated by diagnostic electrophysiology study.

Study Limitations
The present study was retrospective in its data collection. However, the objective of the study was to determine the role of the atrial flutter isthmus in supporting the reentrant circuit in congenital heart surgery survivors. In this respect, these patients were approached prospectively, as evaluation of the atrial flutter was part of the plan at the time of the diagnostic electrophysiologic study. Other sites were evaluated only when the atrial flutter isthmus had been excluded as the critical isthmus by entrainment mapping. Thus, although we know the role of the atrial flutter isthmus in each of these patients, we do not know the role of other portions of the atrium (eg, the superior vena cava–right atrial junction), except in those patients who had the atrial flutter isthmus excluded by entrainment mapping. Therefore, this study does not rule out the potential for successful ablation directed at alternative sites even in patients whose circuits involve the atrial flutter isthmus. However, the important point remains that a large percentage of patients with IART after surgical repair of congenital heart disease have a reentrant circuit that uses the atrial flutter isthmus.

Our patients were not randomized to 2 distinct approaches of either mapping the atrial flutter isthmus first or evaluating the atriotomy sites initially. This prevents a head-to-head comparison of the two approaches. However, as with the prior series, our study included consecutive patients with stable tachyarrhythmias undergoing attempted RFA. This should have limited possible bias in the selection of patients for ablation.

Conclusions
We have shown that in the majority of postoperative patients in our study, the atrial flutter isthmus was part of the reentrant circuit. The fact that the atrial flutter isthmus is a vulnerable target for successful ablation suggests that whenever IART occurs late after repair of a congenital heart defect, one should evaluate the involvement of the atrial flutter isthmus in the reentrant circuit. This does not mean that true incisional reentry does not occur, nor that more than 1 potential reentrant circuit cannot be present, nor that other approaches to cure IART may not be useful or appropriate. However, with recent advances in both our understanding of the nature of the atrial flutter isthmus and in the assessment of successful isthmus ablation, a reasonably high likelihood of long-term successful ablation in such patients should be expected. Furthermore, recognition of the importance of the atrial flutter isthmus for maintenance of IART in these patients invites consideration of intra-operative methods to prevent postoperative occurrence of IART. The most obvious consid-
eration would be to place a lesion in the atrial flutter isthmus prophylactically at the time of surgery. Other potential considerations relate to placement of the atriotomy incision in such a way that it cannot act as a stable line of block between the vena cavae. Finally, these data lend still more support to the theoretical concept that some form of conduction block between the vena cavae is essential for the establishment of a stable substrate for the classic atrial flutter reentrant circuit.

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References


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