Why a Sawtooth? Inferences on the Generation of the Flutter Wave during Typical Atrial Flutter Drawn from Radiofrequency Ablation

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Background: Typical atrial flutter (AFL) is a macroreentrant arrhythmia characterized by a counterclockwise circuit that passes through the cavotricuspid isthmus with passive depolarization of the left atrium. These electrical events are thought to be responsible for the classic "sawtooth" wave of atrial flutter seen on the surface electrocardiogram characterized by a gradual downward deflection followed by a sharp negative deflection. It has been suggested that the negative flutter wave is a result of passive depolarization of the left atrium. We hypothesized that interruption of the circuit within the isthmus would prevent the reentrant wave from depolarizing the left atrium thus eliminating the component of the electrocardiogram reflecting left atrial depolarization.

Methods: We examined 100 cases of atrial flutter with the typical "sawtooth" pattern referred for radiofrequency ablation. Ninety-seven of the 100 were successfully ablated. All cases were reviewed for termination of atrial flutter with the last intracardiac electrogram just lateral to the site of linear ablation and surface flutter wave at the moment of termination not obscured by the QRS segment or the T-wave. Seventeen of the 97 met these criteria.

Results: Seventeen of the 17 cases demonstrated a gradual negative deflection as the last discernible wave of atrial activity followed by an isoelectric period and resumption of normal sinus rhythm. The last generated wave lacked the sharp negative downstroke.

Conclusion: These results suggest that the sharp negative deflection of flutter waves likely correlates with the wavefront's penetration of the interatrial septum and passive depolarization of the left atrium.

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Typical isthmus-dependent atrial flutter is a macroreentrant circuit that propagates in a counterclockwise direction around the right atrium, utilizing the cavotricuspid isthmus in an obligate manner. On the surface electrocardiogram, the atrial flutter wave forms a "sawtooth" pattern in the inferior leads (Fig. 1). This pattern is composed of a two-phased descent and a rapid ascent, with no isoelectric interval. The initial descent is gradual, followed by a sharp, steep component. Although the electrocardiographic appearance of atrial flutter has been described for close to a century, the relative contributions of the left and right atrium to this pattern have been poorly described.

In order to elucidate the origin of the sawtooth pattern of atrial flutter, we analyzed the electrocardiographic appearance of flutter waves during radiofrequency ablation. It is widely believed that the main component of the wave, the sharp descent, represents passive left atrial depolarization in a caudal to cranial direction. We speculated that interruption of the circuit of typical atrial flutter within the cavotricuspid isthmus would prevent the reentrant wavefront from penetrating the interatrial septum and the left atrium. This would result in elimination of that component of the surface electrocardiogram reflective of left atrial depolarization. If this were true, we

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Figure 1. 12-lead electrocardiogram of typical atrial flutter. The arrowhead marks the gradual descent and the arrow marks the steep descent.

hypothesized that using radiofrequency energy to create a linear lesion across the cavotricuspid isthmus would result in termination of atrial flutter during the period of gradual decline on the surface electrocardiogram with no subsequent sharp flutter component.

METHODS

We retrospectively reviewed 100 cases of typical atrial flutter referred to our laboratory for electrophysiologic study and radiofrequency ablation between July 1997 and June 1999. Cases were included if they met the customary surface electrocardiographic and intracardiac electrogram appearances of typical (counterclockwise) atrial flutter. All patients provided informed consent as per New York University Medical Center policy.

Diagnostic electrophysiologic catheters were positioned in standard positions for atrial flutter ablation. In all patients, a 7F steerable catheter with 20 poles using 2/8mm spacing (Daig Corporation, Minnetonka, MN) was positioned around the tricuspid annulus with its tip in the coronary sinus. A 7F ablation catheter with a 4 mm tip (EP Technologies Inc.,

San Jose, CA) was advanced through a long supporting sheath (Daig Corporation) and positioned in the cavotricuspid isthmus. Radiofrequency energy was applied to the cavotricuspid isthmus in a linear fashion during either induced or spontaneously occurring atrial flutter.

Cases were then reviewed for (1) termination of atrial flutter with the last intracardiac electrogram of tachycardia occurring just lateral to the site of linear ablation and (2) a surface flutter wave at the moment of termination unobscured by either the QRS or the T wave.

RESULTS

Radiofrequency ablation of the cavotricuspid isthmus resulted in the termination of atrial flutter in 97 of the 100 patients. Bidirectional block persisted following a minimum 50-minute waiting period following termination of the tachycardia. Seventeen of the 97 successfully ablated patients demonstrated a terminal flutter wave unobscured by the QRS or the T wave as well as termination of the reentrant wavefront just lateral to the site of radiofrequency ablation.

Figure 2. 12-lead electrocardiogram of the termination of atrial flutter during radiofrequency ablation. The last flutter wave is distinct from the QRS and T wave. The terminal flutter wave ends with a gradual descent, without a sharp descending component.

In all 17 patients (100%) the last discernible wave of atrial activity on the surface electrocardiogram was a gradual negative deflection followed by an isoelectric period with subsequent resumption of sinus rhythm. The sharp downstroke was notably absent (Fig. 2).

DISCUSSION

Although Einthoven recorded an electrocardiogram of atrial flutter in 1906, Jolly and Ritchie first described the arrhythmia in 1911.¹⁻³ They reported the typical sawtooth appearance of the electrocardiogram, distinguishing it from atrial fibrillation. A decade later, Lewis further described the electrocardiographic appearance of the atrial flutter wave: "At each cycle in leads II and III the curve ascends sharply to a blunt summit and returns more gradually. . . The gentle downstroke is often notched. . ." separating the slow and the sharp descents.⁴ Lewis surmised that atrial flutter was essentially a "simple circus movement" around one or both caval orifices.⁵

Experimental animal and human models performed in the 1970s led to the current understanding of atrial flutter as a macroreentrant circuit with a counterclockwise rotation around the right atrium. In typical isthmus-dependent, counterclockwise atrial flutter, the wavefront of right atrial activity proceeds through the cavotricuspid isthmus in a lateral-to-medial direction and then propagates up the interatrial septum at the same time that the left atrium is passively depolarized from the coronary sinus in a caudocranial wavefront.⁶ These two events are thought to be responsible for the genesis of the typical sawtooth wave of atrial flutter seen on the surface electrocardiogram characterized by a gradual downward deflection followed by a sharp negative deflection in the inferior leads.

Three-dimensional electroanatomic mapping provides support to this explanation.⁷ Mapping of 17 patients in typical atrial flutter demonstrated variable activation of the posterior right atrium and interatrial septum. This finding suggests that the pathognomonic electrocardiographic appearance

of the flutter wave is a manifestation of the consistent lateral-to-medial activation across the cavotricuspid isthmus and passive activation of the left atrium via the coronary sinus.

Other investigators have tried to elucidate the origin of the flutter wave, using both atrial mapping and clinical observations. SippensGroenewegen et al. performed a 62-lead body surface mapping on patients undergoing electrophysiologic study for atrial flutter.⁸ They concluded that the steep component of the atrial flutter wave corresponds to activation of the interatrial septum in a caudocranial fashion and proximal-to-distal activation of the coronary sinus (i.e., impulse exit from the cavotricuspid isthmus to the left atrium).

Zrenner et al. reported some further evidence of the role of left atrial depolarization in the formation of the flutter wave based on observations during ablation of typical atrial flutter.⁹ The procedure was performed while mapping the right atrium with a basket catheter capable of recording activity from the entire right atrium simultaneously. While delivering energy near the coronary sinus os, the morphology of the flutter waves abruptly changed (from inverted in the inferior leads to upright) to appear like a clockwise flutter. At the same time, the activation pattern throughout the right atrium was unchanged. Zrenner postulated that the right atrial to left atrial connection via the coronary sinus was ablated and that left atrial activation could only occur through Bachman's Bundle. This would have created left atrial depolarization to occur in a cephalad-to-caudal direction, which is presumably the site of left atrial activation during isthmus-dependent, clockwise atrial flutter. The lack of change in the right atrial depolarization supports the hypothesis that the predominant ECG wave is a manifestation of passive left atrial depolarization. Further ablation in the isthmus resulted in the termination of the arrhythmia with subsequent confirmation of electrical block in the cavotricuspid isthmus.

The current study evaluates the electrocardiogram of atrial flutter during termination by radiofrequency ablation of the cavotricuspid isthmus. In all 17 electrocardiograms analyzed, the gradual downstroke of the flutter wave was followed by an isoelectric period. The lack of the sharp negative component correlates with loss of conduc-

tion through the cavotricuspid isthmus to the left atrium.

There are some limitations to this study. No systematic mapping was performed outside the reentrant circuit and thus no inferences can be made concerning variations in right atrial depolarization in these patients. In addition, our results do not eliminate the possibility that the sharp negative descent of the flutter wave is a manifestation of the caudocranial depolarization of the interatrial septum alone. This is unlikely, however, given the small mass of the septum in relation to the rest of the atria, particularly the left atrium, in the genesis of this wave.

Despite these limitations, our results provide evidence to support the theory that the gradual negative deflection of flutter waves during typical isthmus-dependent, counterclockwise atrial flutter represents conduction through the cavotricuspid isthmus, while the subsequent sharp negative deflection pathognomonic of flutter likely correlates with the penetration of the wavefront through the coronary sinus and interatrial septum with passive depolarization of the left atrium.

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