Intra-Isthmus Re-entry: Beyond the Predictability by Atrial Flutter Wave Morphology on Surface Electrocardiogram

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ABSTRACT. Surface electrocardiogram (ECG) is routinely used for assessment of atrial flutter including typical counterclockwise (CCW) cavotricuspid isthmus (CTI)-dependent atrial flutter, manifesting as an inverted sawtooth F-wave pattern in the inferior ECG leads II, III, and aVF, and an upright F wave in the precordial lead V1. However, the surface ECG presentation does not reliably predict the mechanism of atrial flutter, especially in the setting of intra-isthmus entry. We herein present a clinical case in which the electrophysiology study demonstrated a simultaneous CCW and clockwise (CW) pattern occurring during spontaneous atrial flutter despite the typical CCW CTI-dependent atrial flutter appearance on the surface ECG. Earliest atrial activation and double potentials occurred around the ostium of the coronary sinus (CS). Entrainment mapping suggested a micro re-entrant circuit localized to the CTI–CS ostium region, consistent with intra-isthmus re-entry atrial flutter. Radiofrequency energy applications led to elimination of atrial flutter without recurrence during follow-up.

KEYWORDS. atrial flutter, intra-isthmus re-entry, surface electrocardiogram.

Introduction

Atrial flutter has been traditionally referred to as a regular tachycardia with a cycle length shorter than 250 ms and the absence of an isoelectric baseline in at least one lead on the surface electrocardiogram (ECG). Typical atrial flutter, namely counterclockwise (CCW) cavotricuspid isthmus (CTI)-dependent atrial flutter, manifests as an inverted sawtooth F-wave pattern in the inferior ECG leads II, III, and aVF, and an upright F wave in the precordial lead V1. Surface ECG has been considered as a good indicator for CTI-dependent atrial flutter with more than 90% positive predictive value. CTI-dependent atrial flutter includes CCW and clockwise (CW) re-entrant circuits around the tricuspid annulus (TA), and, less commonly, lower loop re-entry or double loop re-entry. Most recently, an intra-isthmus re-entry has been proposed. Here, we present a clinical case with atrial flutter utilizing an intra-isthmus re-entrant circuit despite a presentation of typical counterclockwise CTI-dependent atrial flutter on the 12-lead surface ECG.

Case study

A 77-year-old white male with a history of coronary artery bypass surgery, transient ischemic attack, type 2 diabetes, morbid obesity, obstructive sleep apnea, and hypertension, presented with exertional dyspnea. The 12-lead surface ECG (Figure 1) showed negative sawtooth F wave in inferior leads II, III, and aVF and positive F wave in lead V1, suggestive of typical CCW CTI-dependent atrial flutter. The patient was on a β-blocker but not on oral anticoagulant. He had never been on amiodarone. A transesophageal echocardiogram excluded left atrial appendage thrombus prior to the electrophysiology study. Surface ECGs and intracardiac electrocardiograms were continuously displayed on a computer-based digital recorder system (Cardiolab, General Electric Company, Freiburg, Germany).
Germany). Electrical stimulation was performed with a Bloom electrophysiology stimulator (Model DTU-215B, Fischer Imaging Corp, Denver, CO). Via the right femoral vein, two 8.5-French and one 7.5-French sheaths were placed. Through the 8.5-French sheath, an 8-French deflectable duodecapolar catheter with 2-mm interelectrode spacing and 5-mm spacing between bipoles (Daig Corp., Minnetonka, MN) was situated in the right atrium and along the tricuspid annulus, with the proximal pole close to the sinus node in the lateral right atrium and the distal pole in the distal portion of the CS. Through the 7.5-French sheath, a medium curve quadripolar catheter was placed to the His bundle area. A bidirectional 8-mm tip Safire catheter (St. Jude Medical, Inc., St. Paul, MN) was employed for ablation. Radiofrequency energy applications (50–70 W, 30–60 s per application) were performed sequentially to produce a linear lesion. After ablation, burst pacing was performed from more than two sites at a cycle length...
decreased by 10 ms per burst from 300 ms to 240 ms. The example of intracardiac catheter positions are illustrated in the fluoroscopic views with right and left oblique projections (Figure 2).

The baseline ECG showed typical atrial flutter with tachycardia cycle length (TCL) of 230 ms (Figure 1). However, the endocardiogram showed spontaneous atrial flutter with the earliest breakthrough occurring around the ostium of coronary sinus (CS) (M4) and wavefronts in simultaneous CCW and CW forms colliding at the superior portion of the right atrium (Figure 3). The double potentials were also present in M4, consistent with a slow-conduction zone involved with atrial tachyarrhythmia. The double potentials from the ostium of CS may represent the pivot point around the CS and thus a successful ablation site.\textsuperscript{8} Figures 4 and 5 showed concealed entrainment during overdrive pacing at M4 with a cycle length of 190 ms. The post-stimulation intervals (PPI) were 230 ms at M3 and 254 ms at M5, respectively. When the PPI–TCL <10 ms, the pacing site is considered

**Figure 3:** An intracardiac electrogram from His bundle, ablation, and duodecapolar catheters, and surface ECG of leads I, II, V\textsubscript{1}, and V\textsubscript{6} demonstrating spontaneous atrial flutter (tachycardia cycle length [TCL] = 230 ms) with earliest atrial activation at M4 and simultaneous counterclockwise (to His) and clockwise (to M10) wavefronts colliding at the high right atrium. The wavefront also traveled from the ostium of CS to the distal CS. The double potentials (x and y) with an interval of 65 ms were recorded at M4. The schematic diagram on the top showed the bipolar electrode positions of the duodecapolar catheter, the sequence of atrial activation (dashed arrows) and the speculated re-entrant circuit (solid arrows). TA = tricuspid annulus.
Figure 4: Simultaneous recording of the surface ECG (leads I, II, V1, and V6) and intracardiac electrogram from the His bundle, ablation, and duodecapolar mapping catheters during pacing from M4. Pacing at the cycle length (CL) of 190 ms resulted in concealed entrainment, confirming a re-entrant mechanism for tachycardia.

Figure 5: The intracardiac electrogram showing the site at M4 within the circuit. The post-pacing interval (PPI) was 230 ms and PPI-TCL was 0 ms at M3. The PPI was 254 ms and PPI-TCL was 24 ms at M5. These suggest that M4 was located at an ablation target. EGMs in this figure immediately followed those in Figure 4. It was continuously entrained at the beginning with CL of 190 ms, but the loss of capture was seen for three beats near the end of entrainment (see discussion) before the last two beats were entrained.
definitely within the circuit. Concealed entrainment with PPI–TCL <25 ms at other sites was unable to be achieved. This suggests an intra-isthmus circuit confined to the septal CTI and/or around the ostium of CS. Radiofrequency applications were applied around the ostium of the CS. Subsequently, tachycardia was terminated and bidirectional isthmus block was achieved (Figure 6). The presence of double potentials with an interval of 115 ms recorded in the ablation catheter before termination suggested a bidirectional isthmus block (Figure 6). Consequently, sinus rhythm was restored (Figure 7). The double potentials (widely spaced >90–110 ms) along the ablation line across CTI are generally regarded as the gold standard for complete bidirectional block. In addition, the atrial flutter could not be induced with pacing either at the high right atrium or distal CS. The patient had no episodes of recurrent atrial flutter at the last follow-up of 18 months with two consecutively negative 24-h Holter ECGs.

**Discussion**

Surface ECG has been frequently used to predict CTI-dependent atrial flutter. Although a typical CCW atrial flutter was suggested by the surface ECG with an inverted sawtooth F-wave pattern in the inferior ECG leads II, III, and aVF, as well as an upright F wave in the precordial lead V1, endocardial electrograms revealed atrial flutter with a simultaneous CCW and CW pattern in this case. The atrial flutter wave morphology on the surface may be related to the atrial septal activation in the inferosuperior direction (Figure 3). Nevertheless, the polarity of atrial flutter wave on the surface ECG has been thought to be primarily determined by the activation sequence of the left atrium.

The recent study by Yang et al. showed that 4% of patients with CTI-dependent atrial flutter had intra-isthmus re-entry, and 1% of those manifested simultaneous CCW and CW pattern and symmetrical activation of septal and lateral right atrial annular sites. In the majority of these cases with the intra-isthmus re-entry, a micro re-entrant circuit has been considered to be localized to the CTI–CS ostium region. The simultaneous CCW and CW pattern with wavefronts colliding at the zone that is out of the essential re-entrant circuit. It was demonstrated that successful ablation sites were associated with double potentials or fractional potentials of longest duration. In the majority of the cases with intra-isthmus re-entry, such as the present study, the micro re-entrant circuit was localized to the CTI–CS ostium region, although it did not always appear.
In this case, earliest atrial activation around the ostium of CS and double potentials recorded at the same position supported a critical zone of slow conduction. This was further validated by the success of atrial flutter elimination via radiofrequency application at the site near the ostium of CS. Failure to capture might occur at times in some critical regions of a re-entrant circuit (Figure 5).\(^{14}\) It may be associated with the effective refractory period. This might be minimized by pacing at 10–30 ms less than the TCL, instead of the 40 ms used in this patient. Regardless, radiofrequency energy applied at this site eliminated the tachycardia. In the present case, the sequence of CS activation was from the proximal to distal. The correlation of atrial flutter wave morphology on the surface ECG with the orientation of CS activation sequence remains unclear.\(^{7}\) The activation of CS does not appear to be a critical determinant for surface ECG presentations.\(^{7}\)

Despite the regular employment of surface ECGs for initial evaluation of atrial flutter in routine medical practice, it is important to recognize that a typical pattern of CCW atrial flutter on the surface ECG has its considerable limitations. The newly described intra-isthmus re-entry provides an important supplement to the mechanisms for CTI-dependent AFL. It was noted that it might be related to idiopathic or acquired fibrosis including scarring secondary to previous ablation procedures or cardiac surgery. Such a lesion occurs occasionally with coronary surgery.\(^{15}\) The venous drainage could be via a cavoatrial cannula, which is inserted into the right atrium.\(^{16}\) The low amplitude of flutter wave in the surface ECG (Figure 1) might reflect atrial scar tissue. It is unclear whether the coronary artery bypass surgery of our patient contributed to an acquired lesion that predisposed to development of intra-isthmus re-entry. However, although the precise anatomic circuit of intra-isthmus re-entry remains to be elucidated, recognition of this mechanism is certainly a valuable addition to the arsenal of thoughts, particularly in the clinical settings of unusual intracardiac activation sequence or recurrent atrial flutter after a previous ablation, albeit successful.

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**References**


