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Heart Rhythm Disorders

A New Electrocardiographic Algorithm to Differentiate Upper Loop Re-Entry From Reverse Typical Atrial Flutter

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OBJECTIVES This study was performed to differentiate upper loop re-entry (ULR) from reverse typical atrial flutter (AFL).

BACKGROUND Right atrial ULR and reverse typical AFL have different mechanisms and ablation strategies, but similar electrocardiographic characteristics.

METHODS This study included 26 patients with reverse typical AFL and 20 patients with ULR. The noncontact mapping system (EnSite-3000, Endocardial Solutions, St. Paul, Minnesota) was used to confirm diagnosis and guide successful radiofrequency ablation. Flutter wave polarity and amplitude in the 12-lead surface electrocardiogram were determined by two independent electrophysiologists.

RESULTS The flutter wave polarity in leads I and aVL was significantly different between the reverse typical AFL and ULR groups ($p \leq 0.001$). Voltage measurement revealed significant differences between reverse typical AFL and ULR in leads I, II, aVR, aVF, V_1, and V_2 ($p < 0.001$). A new diagnostic algorithm based on negative or isoelectric/flat flutter wave polarity and amplitude ≤0.07 mV in lead I was useful for diagnosis of ULR, with an accuracy of 90% to 97%, a sensitivity of 82% to 100%, and a specificity of 95%.

CONCLUSIONS Polarity and voltage measurement of flutter wave in lead I can differentiate reverse typical AFL from ULR. (J Am Coll Cardiol 2005;46:524–8) © 2005 by the American College of Cardiology Foundation

It is well known that typical atrial flutter (AFL) has negative flutter waves in leads II, III, and aVF and positive flutter waves in lead V_1 (1,2). In contrast, reverse typical AFL has positive flutter waves in inferior leads and negative flutter waves in lead V_1 (2–4); however, atypical AFL involving the upper portion of the right atrium, namely upper loop re-entry (ULR), also has similar electrocardiographic (ECG) characteristics (5). Distinguishing ULR from reverse typical AFL would be clinically important, because they must be treated by different mapping techniques and ablation approaches. Therefore, the purpose of this study was to develop an ECG algorithm to differentiate reverse typical AFL from ULR.

METHODS

Patient characteristics. From January 2000 to December 2002, 260 consecutive patients with symptomatic AFL underwent electrophysiological study and radiofrequency catheter ablation. There were 28 patients with ULR and 60 with reverse typical AFL. The study population consisted of 20 patients with ULR and 26 patients with reverse typical AFL whose ECG showed >2:1 atrioventricular (AV) block during AFL. All of the 46 patients had high flutter wave amplitude in the inferior ECG leads, therefore, the possibility of left AFL was ruled out (6). There were 33 men and 13 women, with a mean age of 60 ± 16 years. Of 20 ULR patients, 12 had cardiovascular diseases, including 2 with coronary artery disease, 6 with hypertension, 1 with hypertrophy cardiomyopathy, and 3 with congestive heart failure. Of 26 reverse typical AFL patients, 10 had cardiovascular diseases, including 2 with coronary artery disease, 6 with hypertension, and 2 with congestive heart failure.

Electrophysiological study. Informed written consent was obtained from all patients. As described previously, all antiarrhythmic drugs were discontinued for at least five half-lives before the study (5). In all patients a 7-F, 20-pole, deflectable Halo catheter with 10-mm paired spacing (Cordis-Webster, Baldwin Park, California) was positioned around the tricuspid annulus to record the right atrial activation in the lateral wall and the cavotricuspid isthmus (CTI) simultaneously. A 7-F, nondeflectable decapolar catheter with 2-mm interelectrode distance and 5-mm space between each electrode pair was also inserted into the coronary sinus via the internal jugular vein. The position of the proximal electrode pair at the ostium of the coronary sinus was confirmed with contrast injection. A 9-F sheath

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Abbreviations and Acronyms

AFL = atrial flutter
AV = atrioventricular
CTI = cavotricuspid isthmus
ECG = electrocardiogram/electrocardiographic
MEA = multi-electrode array
ROC = receiver-operating characteristic
SVC = superior vena cava
ULR = upper loop re-entry

placed in the left femoral vein was used to introduce the noncontact mapping catheter.

The noncontact mapping system was previously described in detail (5). In brief, the system consists of a noncontact catheter (9-F) with a multi-electrode array (MEA) surrounding a 7.5-ml balloon mounted at the distal end. Raw data detected by the MEA is transferred to a silicon graphics workstation via a digitalized amplifier system. Heparin boluses were given according to activated clotting time value to maintain an activated clotting time between 200 and 250 s throughout the study. The MEA catheter was deployed over a 0.035-inch guidewire, which had been advanced to the superior vena cava (SVC). The system locates any catheter in relation to the MEA with a "locator" signal, which serves two purposes. It is used to construct a three-dimensional computer model of the virtual endocardium, providing a geometry matrix for the inverse solution. Geometric points are sampled at the beginning of the study during sinus rhythm or AFL. The locator signal is also used to display and track the position of the catheter on the virtual endocardium and allows marking of anatomic locations identified with fluoroscopy and electrographic characteristics. With mathematic techniques to process these potentials, the system is able to reconstruct more than 3,000 unipolar electrograms simultaneously and superimpose them onto the virtual endocardium, producing isopotential maps with a color range representing voltage amplitude. Reconstructed electrograms can also be selected from sites on the virtual endocardium and displayed individually.

Flutter wave analysis. The 12 leads in the surface ECG were recorded simultaneously. A period of at least 3:1 AV block during AFL was chosen for flutter wave analysis. The 12-lead ECG was read and measured at 25 mm/s sweep speed with a filter setting of 0.05 Hz (high pass) and 100 Hz (low pass). The widest flutter wave of any lead was chosen to define the onset and the offset of flutter wave in all other leads. The flutter wave polarity was determined by two independent electrophysiological doctors who did not know the results of electrophysiological studies. Differences in interpretation were resolved by consensus. The isoelectric interval between flutter waves was defined as that interval with a slope of $<30°$ in relation to the horizontal plane (7) or derived from the closest and clearest PR segment. The flutter wave amplitude was measured from the peak to the nadir on the amplified electrograms and averaged from three flutter waves with the electronic calipers on the CardioLab system (Prucka Engineering Inc., Houston, Texas). The voltage of biphasic flutter wave is measured as the sum of negative and positive deflection; if positive and negative components of the flutter wave were equivalent, the flutter wave was termed isoelectric. Flat polarity is amplitude <0.01 mV and more than -0.01 mV (Fig. 1). In every lead, flutter wave was measured three times. Intraobserver and interobserver agreement was calculated.

Diagnostic algorithm. The characteristics of ECGs with tachycardia obtained from 46 patients were correlated with the mechanisms of AFL. A new diagnostic algorithm to differentiate between ULR and reverse typical AFL was developed on the basis of ECG features derived from 46 patients, according to the following progression: first, polarity of flutter wave was chosen as the first criterion, because it is simple to differentiate by the naked eye; second, the amplitude was used to further differentiate equivocal polarities; and finally, the algorithm was constructed. The ECGs of the same patients, but from different time segment, were blindly evaluated by two independent electrophysiological doctors, according to the new diagnostic algorithm. Thirty-one different time segments of ECGs, including 11 ULR and 20 reverse typical AFL, were evaluated. The accuracy was determined, and the intraobserver and interobserver agreement was calculated.

Statistical analysis. Continuous variables are presented as mean ± SD. The Fisher exact test was used to compare the proportion of flutter wave polarity in the different ECG leads of the patients with reverse typical AFL and those with ULR. The *t* test was used to compare the flutter wave amplitude in the different ECG leads between both groups.

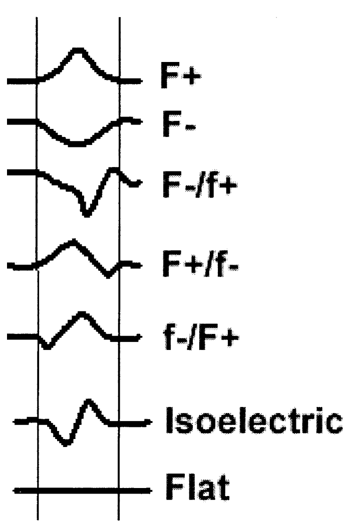

Figure 1. This figure shows schemas of variable flutter wave morphologies on 12-lead electrocardiograms. The first two waves are monophasic positive (F+) and negative (F−) flutter waves. The third through sixth waves are biphasic flutter waves, consisting of dominant negative with small terminal positive (F−/f+), dominant positive with small terminal negative (F+/f−), small initial negative with dominant terminal positive (f−/F+), and the equal amplitude of negative and positive waves (Isoelectric). Flat polarity is amplitude <0.01 mV and more than -0.01 mV.

Table 1. Flutter Wave Polarity in the 12-Lead ECG

	Reverse Typical AFL			ULR			
Lead	**(+)**	**(−)**	**(± or Flat)**	**(+)**	**(−)**	**(± or Flat)**	**p Value**
I	25	0	1	8	3	9	<0.001
II	24	0	2	17	2	1	0.295
III	23	2	1	15	2	3	0.515
aVR	2	24	0	3	16	1	0.363
aVL	10	2	14	2	11	7	0.001
aVF	23	2	1	16	3	1	0.818
V_1	7	14	5	8	4	8	0.064
V_2	11	6	9	9	3	8	0.858
V_3	18	1	7	14	2	4	0.612
V_4	23	0	3	15	3	2	0.174
V_5	25	0	1	14	2	4	0.048
V_6	25	0	1	15	2	3	0.103

AFL = atrial flutter; ECG = electrocardiogram; ULR = upper loop re-entry.

The intraobserver and interobserver agreement in analyzing the polarity of flutter wave was calculated by the κ statistic. The receiver-operating characteristic (ROC) curve was used to find the best cutoff value between ULR and reverse typical AFL. The accuracy of differentiation of AFL mechanisms by the proposed criterion was calculated as the ratio of the number of accurate prediction over the total number of analyzed AFL. A p value <0.05 was considered statistically significant.

RESULTS

Electrophysiological characteristics. The mean tachycardia cycle length of reverse typical AFL was 220 ± 32 ms. The noncontact mapping of reverse typical AFL showed that the activation wave front ascended the anterior wall to the right atrial roof, with broad activation to the SVC, and traveled down the septum. The wave front propagated through the CTI to complete the re-entrant circuit. The

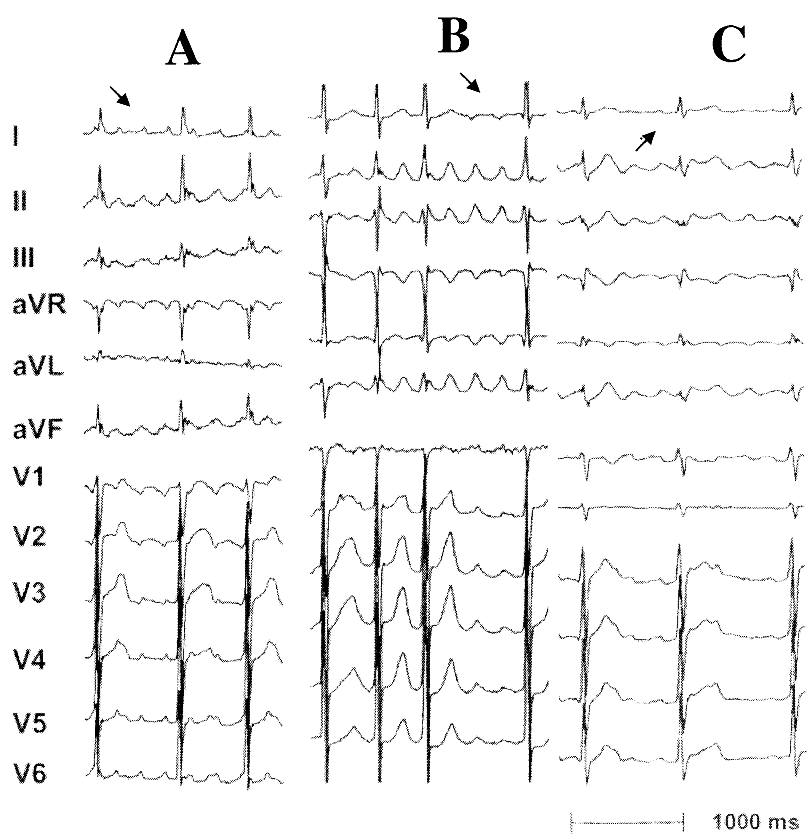

Figure 2. During reverse typical atrial flutter (AFL), the flutter wave in lead I demonstrates prominent (>0.07 mV) positive polarity **(A)**. During upper loop re-entry (ULR), lead I demonstrates either negative flat **(B)** or small (≤0.07 mV) positive **(C)** polarity. Note the similarities of flutter waves in inferior leads between reverse typical and ULR AFL.

mean cycle length of ULR was 207 ± 31 ms. There were 10 counterclockwise ULR and 10 clockwise ULR. During counterclockwise ULR, the activation wave front traveled down the anterior wall and crossed the gap in the crista terminalis, ascended the posterior wall, and turned around the superior vena cava to complete the re-entrant circuit. Patients with clockwise ULR had a reverse activation sequence.

ECG characteristics. POLARITY OF FLUTTER WAVE. The flutter wave polarity in leads I, aVL, and V_5 showed significant differences between ULR and reverse typical AFL (Table 1, Fig. 2). In lead I, 25 patients (96%) with reverse typical AFL demonstrated positive polarity, and only 1 patient had flat polarity. In contrast, during ULR, nine (45%) patients had isoelectric or flat polarity, eight (40%) had positive polarity, and three (15%) had negative polarity.

AMPLITUDE OF FLUTTER WAVE. Except for leads III, aVL, V_3, V_4, and V_6, the amplitudes of all other leads were significantly different between reverse typical AFL and ULR (Table 2). Only lead I showed consistent significant differences of both amplitude and polarity between ULR and reverse typical AFL. The ROC curve analysis of lead I voltage showed that the best cutoff value between ULR and reverse typical AFL was 0.07 mV, which had a sensitivity of 89.3% (95% confidence interval [CI] 80.1 to 95.3) and specificity of 100% (95% CI 92.2 to 100.0) (Fig. 3).

DEVELOPMENT OF THE ALGORITHM. The selected criteria derived from analysis of the tachycardia ECGs were organized into the new diagnostic algorithm (Fig. 4). With the particular algorithm, two independent observers reassessed 31 episodes of AFL from the same previous patients but different time segment recording. The algorithm reached accuracy of 90% to 97%. The sensitivity ranged from 82% to 100%, with a specificity of 95%, and positive predictive values ranged from 90% to 92%. The κ values representative of the intraobserver and interobserver agreement were 0.77 to 0.93 ($p < 0.001$) and 0.86 ($p < 0.001$), respectively.

Table 2. Flutter Wave Amplitude in the 12-Lead ECG

Lead	Amplitude (mV) ULR	Amplitude (mV) Reverse Typical	p Value
I	0.0078 ± 0.0448	0.1172 ± 0.0377	0.000
II	0.1561 ± 0.0504	0.2035 ± 0.0583	0.000
III	0.1596 ± 0.0510	0.1771 ± 0.0580	0.095
aVR	−0.0885 ± 0.049	−0.1416 ± 0.080	0.000
aVL	−0.0435 ± 0.080	−0.0192 ± 0.081	0.114
aVF	0.1167 ± 0.0985	0.1529 ± 0.0897	0.000
V_1	0.0826 ± 0.1008	−0.0491 ± 0.135	0.000
V_2	0.0948 ± 0.0728	−0.0137 ± 0.111	0.000
V_3	0.1073 ± 0.0639	0.0891 ± 0.0930	0.248
V_4	0.1236 ± 0.0483	0.1251 ± 0.0608	0.890
V_5	0.1078 ± 0.0474	0.1301 ± 0.0564	0.027
V_6	0.1160 ± 0.0631	0.1336 ± 0.0512	0.098

Abbreviations as in Table 1.

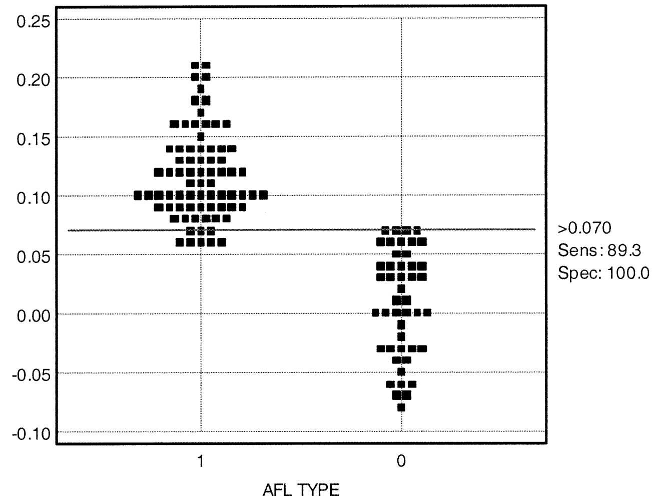

Figure 3. This dot diagram shows voltage amplitude distribution of flutter wave in lead I. Receiver-operating characteristic analysis found that a cutoff point of >0.07 mV has a sensitivity (Sens) 89.3% and a specificity (Spec) of 100% in differentiating between reverse typical atrial flutter (group 1) and upper loop re-entry (group 0). AFL = atrial flutter.

DISCUSSION

Main finding. This study showed that negative or flat flutter wave polarity in lead I favored ULR, whereas positive polarity with amplitude of more than 0.07 mV indicates reverse typical AFL. The new diagnostic algorithm based on polarity and amplitude of flutter wave in lead I was highly accurate in differentiating ULR from reverse typical AFL.

Mechanism of lead I differentiation. Several experimental and human studies have demonstrated that the flutter wave polarity in the ECG is determined primarily by the activation sequence in the left atrium (8–11). During reverse typical (clockwise) AFL, the right atrial free wall is electrically silent when the left atrium, including the atrial septum, is activated in the leftward and downward directions, similar to activation during sinus rhythm (12,13). Therefore, the polarity of flutter waves in lead I is positive, because the activation direction faces toward lead I. In contrast, during

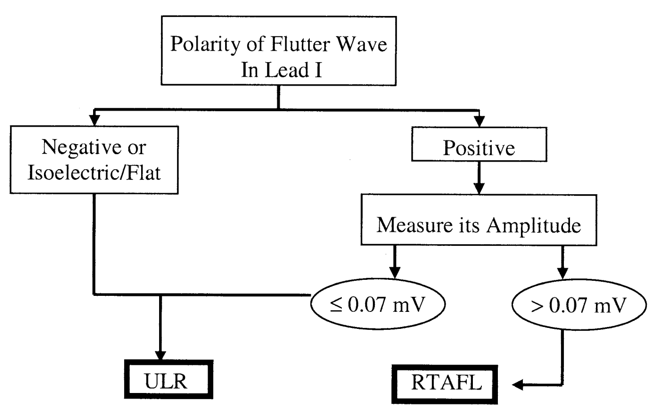

Figure 4. The new diagnostic algorithm to differentiate between upper loop re-entry (ULR) and reverse typical atrial flutter (RTAFL). Flat polarity is defined as polarity of <0.01 mV, but more than −0.01 mV. Isoelectric is defined as biphasic polarity in which negative and positive deflection has equal amplitude.

clockwise ULR, the right atrium, including its free wall, is activated in the rightward direction via the gap in the crista terminalis and the upward direction when the left atrium is activated in the leftward and downward directions. Thus, these two oppositely directing and simultaneously propagating wave fronts seem to cancel the polarity of each other, resulting in flat, negative, or low-amplitude positive wave in lead I. During counterclockwise ULR, there might be variable activation of the left atrium by the wave front from the mid or low interatrial septum. Therefore, the polarity of flutter waves in lead I can be flat, negative, or low-amplitude positive. This has been demonstrated in the previous study by Waldo et al. (14).

Clinical implications. Various forms of AFL have been reported, and several diagnostic criteria to differentiate them have been proposed as well. Positive flutter wave in inferior leads could be found in left atrial, ULR, and reverse typical AFL. Left AFL can be distinguished from right AFL on the basis of amplitude of flutter wave in the inferior ECG leads (6). The proposed ECG algorithm would be useful to further distinguish ULR from reverse typical AFL. Estimating the mechanisms of AFL would provide for better advanced planning, because these two tachycardias require absolutely different mapping and ablation techniques.

Study limitations. The study population comprised only AFL with >2:1 AV block patients; therefore, the ECG algorithm might not be applied on AFL patients with 1:1 or 2:1 AV conduction, whereas the flutter wave morphology might be inferred by T-wave.

Conclusions. The present study showed that polarity and amplitude of a flutter wave in lead I of the 12-lead ECG could differentiate CTI-independent ULR from CTI-dependent reverse typical AFL.

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