ORIGINAL ARTICLES

Atypical Electrocardiographic Features of Cavotricuspid Isthmus-Dependent Atrial Flutter Occurring during Left Atrial Fibrillation Ablation

Janice Y. Chyou, M.D.,* Kathleen Hickey, A.P.R.N., Ed.D.,‡
Laurence Diamond, M.B., B.Ch.,† William Whang, M.D., M.S.,‡ Jose Dizon, M.D.,‡
Hasan Garan, M.D., M.S.,‡ and Angelo Biviano, M.D., M.P.H.‡

From the *Department of Medicine, Brigham and Women's Hospital, Harvard Medical School, Boston, MA;
†General Practice, Antrim Area Hospital, Northern Ireland; and ‡The Department of Medicine, Division of
Cardiology, Columbia University College of Physicians and Surgeons, New York, NY

Background: Patients who have undergone percutaneous catheter ablation for atrial fibrillation (AF) may develop cavotricuspid isthmus (CTI)-dependent atrial flutter (AFL), which can occur either spontaneously during left atrial (LA) ablation for AF or by induction from sinus rhythm during the procedure. The electrocardiographic (ECG) characteristics of CTI-dependent AFL occurring during LA ablation have not been described. The purpose of this study was to describe the ECG features of CTI-dependent AFL occurring during percutaneous LA catheter ablation for AF.

Methods and Results: Of 223 patients presenting for first AF ablation at our institution between May 2004 and February 2008, 20 patients (9%) developed CTI-dependent AFL during LA ablation for AF. CTI-dependent AFL developed spontaneously in 4 patients (20%) and was induced in 16 patients (80%). Among these 20 patients, 3 (15%) had typical ECG patterns and 17 (85%) had atypical ECG patterns. Flutter waves in the inferior leads were biphasic in 10 patients (50%), downward in 3 patients (15%), positive in 3 patients (15%), and not fitting the above classifications in 4 patients (20%). There was no statistically significant association between AFL pattern and LA size, left ventricular ejection fraction, total ablation time, duration of prior AF, or type of prior AF.

Conclusion: A majority of patients with CTI-dependent AFL occurring during LA ablation have atypical ECG patterns. Biphasic flutter waves in the inferior leads are common ECG features, occurring in one-half of patients. Right atrial CTI-dependent AFL should be suspected even if the ECG appearance is atypical.

Ann Noninvasive Electrocardiol 2010;15(3):200–208

atrial flutter; atrial fibrillation; radiofrequency ablation; ablation; electrocardiography;
cavotricuspid isthmus

Typical atrial flutter (AFL), also known as type I AFL or cavotricuspid isthmus (CTI)-dependent flutter, refers to a right atrial macroreentrant arrhythmia circuit involving the CTI that rotates in a typical counterclockwise (CCW) or reverse typical clockwise (CW) pattern around the tricuspid

annulus, which serves as the anterior boundary for the circuit.¹ Patients who have undergone percutaneous catheter radiofrequency ablation (RFA) for atrial fibrillation (AF) may develop CTI-dependent AFL after left atrial (LA) ablation for AF.² ECG characteristics of CTI-dependent AFL developing

Address for correspondence: Angelo Biviano, M.D., M.P.H., Department of Medicine, Division of Cardiology, Columbia University Medical Center, Fort Washington Avenue, Milstein 5th Floor, Room 435-F, New York, NY, 10032. Fax: (212) 342-3591; E-mail: ab542@columbia.edu

Sources of financial support: None.

Conflicts of interests: None.

©2010, Wiley Periodicals, Inc.

several months after LA ablation for AF have been reported.² However, ECG characteristics of CTI-dependent AFL occurring during LA ablation have not been previously described. Such insight may help guide diagnosis in patients who develop AFL during AF ablation. The purpose of this study was to describe the ECG features of CTI-dependent right AFL occurring during LA ablation for AF.

METHODS

Study Design

We retrospectively studied a series of patients who developed CTI-dependent AFL during LA ablation for AF at Columbia University Medical Center between May 2004 and February 2008. AF was defined by irregular cycle length, morphology, and activation on a beat-to-beat basis, while AFL manifested a regular cycle length, morphology, and activation sequence.³ Adult patients > 18 years of age undergoing LA ablation for AF who developed AFL for greater than 5 minutes duration either spontaneously or during postablation induction maneuvers were included in the study. Patients with prior cardiac surgery or cardiac ablation procedures were excluded from the study.

AF Mapping and Ablation

AF Mapping

LA catheter ablation of AF was performed using a strategy of pulmonary vein isolation (PVI)^{4,5} or LA circumferential ablation.⁶ All patients underwent anticoagulation for at least 1 month, with a goal INR between 2.0 and 3.0. Antiarrhythmic medications were stopped for at least five half-lives before the study. Electrophysiology study was performed using conscious sedation with midazolam and fentanyl during catheter access and atrial mapping. Surface ECG and endocardial electrograms were monitored and stored on a digital recording system (Cardiolab, Prucka GE, WI, USA). Intracardiac electrograms were filtered from 30 to 500 Hz at a sweep speed of 100–200 mm/sec.

The LA was accessed using a transseptal technique, and heparin IV bolus was administered to achieve an ACT goal >300 seconds. LA mapping was performed using either a quadripolar electrode catheter with an 8-mm nonirrigated tip (Navistar; Biosense Webster Diamond Bar, CA, USA) or 4-mm irrigated tip electrode (Navistar Thermocool;

Biosense Webster) and the CARTO 3-dimensional electroanatomic mapping system (Biosense Webster). For cases where PVI was confirmed, a second transseptal puncture was performed, and a circumferential decapolar mapping catheter (Lasso, Biosense Webster) utilized in order to confirm PVI. In addition, a deflectable octapolar catheter was positioned within the coronary sinus (CS), and a decapolar circumferential mapping catheter was positioned along the tricuspid annulus. Deep sedation and/or general anesthesia, including endotracheal intubation, were performed immediately prior to LA ablation.

AF Ablation

For PVI, ablation was performed as wide circumferential lesions approximately 1 cm from the pulmonary vein ostia, with the procedural end point of elimination or dissociation of pulmonary vein potentials from atrial electrical activity. RFA was performed with temperature/power ranges from 45° C/25 to 35 W (4-mm irrigated tip catheter) or temperature/power ranges of 65° C/45–50 W (8-mm non-irrigated tip catheter). No additional linear or point lesions were performed in the atria prior to assessment for the presence of AFL.

AFL Induction, Mapping, Ablation, and ECG Analysis

AFL Induction and Mapping

After RFA for AF was completed, if the underlying rhythm was sinus rhythm, programmed cardiac stimulation was carried out using right and left atrial burst pacing with decremental cycle length until 1:1 atrial capture was lost, or 200 ms pacing cycle length was reached. If AFL was not induced using this protocol, repeat programmed stimulation was performed after intravenous isoproterenol infusion (1–10 µg/min) in order to increase baseline heart rate by at least 50%. AFL was noted on ECG and atrial electrogram analysis in the electrophysiology lab. When AFL with a constant cycle length was induced in using this strategy, the rhythm was defined as *inducible AFL*. At this point, or if the underlying cardiac rhythm after AF ablation transformed from AF to an AFL with stable cycle length (defined as *spontaneous AFL*), analysis for CTI-dependence was performed. First, atrial electrograms were analyzed for right atrial and CS sequence. If this activation sequence was compatible

with isthmus-dependent right AFL, entrainment maneuvers were performed from the right medial and lateral CTI at a cycle length 10–30 ms shorter than the AFL cycle length. If pacing in the CTI resulted in acceleration of atrial rate to the pacing rate with identical P-wave morphologies and activation sequences in the right atrial decapolar and CS catheters, and if the postpacing interval minus AFL cycle length was ≤ 30 ms, the pacing site was deemed to be located in the circuit of the reentrant tachycardia, and defined as CTI-dependent AFL.

AFL Ablation

A strategy of AFL ablation was utilized for patients developing CTI-dependent AFL during or immediately after LA ablation. If entrainment mapping revealed CTI-dependent AFL, ablation was performed in the CTI using radiofrequency energy. RFA was initiated with settings of temperature of 45°C and power of 35–45 W (4-mm irrigated-tip catheter), or temperature 65°C and power 50 W (8-mm nonirrigated catheters). Radiofrequency energy was maintained until the bipolar atrial recording decreased by at least 75%. Before the end of the procedure, the presence of bidirectional block in the CTI was confirmed during pacing from the CS and from the lateral CTI site.

ECG Analysis

The ECG precordial leads were placed in the following standard locations: lead V₁ in right parasternal, 4th intercostal space; lead V₂ in left parasternal, 4th intercostal space; lead V₃ between V₂ and V₄; lead V₄ in midclavicular line, 5th intercostal space; lead V₅ in anterior axillary line, same level as lead V₄; and lead V₆ in midaxillary line, same level as lead V₄). The defibrillation pads were positioned around the precordial leads. The ECG limb leads were placed on the anterior left and right upper arms and hips.

Twelve-lead ECGs of all the CTI-dependent AFLs were analyzed by two investigators (J.D., W.W.), with a third investigator to adjudicate discrepancies (H.G.). The overall ECG AFL patterns were classified as *typical* if either right atrial CTI counterclockwise or clockwise ECG features were present.¹ That is, typical counterclockwise AFL was defined as possessing a characteristic negative sawtooth flutter wave appearance that predominated in the inferior leads and positive component in lead V₁

that became inverted or isoelectric by lead V₆. Reverse typical clockwise AFL was defined as possessing a characteristic positive sawtooth flutter wave appearance that predominated in the inferior leads and negative component in lead V₁ that transitions to positive by V₆. If neither of these two patterns were present, the ECGs were classified as *atypical* in appearance. Polarity of AFL waves in each lead were graded as negative (i.e., lack of a positive component), positive (i.e., lack of a negative component), biphasic (i.e., possessing both negative and positive components), isoelectric (i.e., no predominant polarity), or multicomponent (i.e., complex with multiple polarities).² ECG patterns were also described as *dominant* if the same pattern occurred in at least 2 of the 3 inferior leads (i.e., leads II, III, and aVF).

Statistical Analysis

Statistical analyses were performed with the use of SAS, version 8.2 (Cary, NC, USA). Continuous variables are presented as mean $\pm$ SD and categorical variables as proportions. The significance of differences in means between patients with typical and atypical flutter patterns was analyzed by Student's *t*-test while analysis of variance (ANOVA) was used for patient groups categorized by type of F-wave pattern. Tests of association with categorical variables utilized Fisher's exact test and chi-square test, respectively. Analyses related to paroxysmal versus persistent and spontaneous versus induced AFL utilized Student's *t*-test for continuous variables and Fisher's exact test for categorical variables. A P value < 0.05 was considered significant for all analyses.

RESULTS

Demographics

Clinical characteristics of study patients are summarized in Table 1. A total of 20 patients (15 men, 5 women) undergoing LA ablation had spontaneous or inducible right CTI-dependent AFL during the RFA procedure. The average age of patients was 60.5 ± 8.0 years. Twelve patients had a history of paroxysmal AF and eight patients had persistent AF. Average duration of history of AF was 6.6 ± 6.4 years. All patients underwent RFA while off AADs for at least five half-lives, except for two patients who had remained on amiodarone therapy prior to ablation. Clinical AFL had not been

Table 1. Clinical Characteristics of Study Patients

Patients, n	20
Age, years	60.5 ± 8.0
Male/female, n	15 male, 5 female
History of AF, years	6.6 ± 6.4
History of AFL, n	1
Paroxysmal/persistent, n	12 paroxysmal/8 persistent
LA diameter, cm	4.47 ± 0.33*
LV ejection fraction < 50%, n	3
Rhythm at the beginning of the LA ablation procedure	10 sinus/10 AF
Comorbidity	Number of subjects
Hypertension	6
Mitral regurgitation	4 (2 mild, 1 mild-moderate, 1 moderate)
Hyperlipidemia	2
History of hypothyroidism	2 (both presently euthyroid on synthroid)
Congestive heart failure	1
Chronic obstructive pulmonary disease	1
Diabetes mellitus	1
Patent foramen ovale	1
Permanent pacemaker	1

LV = ventricular; AFL = atrial flutter; data shown are mean ± SD or number of subjects.

*For the three subjects without quantitative data on LA dimension, 1 had no LA diameter information available; 1 was noted to have normal LA dimension, 1 was noted to have “mildly dilated” LA.

documented in any except one of the patients prior to their first catheter ablation procedure for AF (Patient #3, Table 2).

Atrial Fibrillation Radiofrequency Ablation

Wide circumferential ablation around all pulmonary veins was performed in all 20 patients. The mean total AF RFA time was 3612 ± 898 seconds. In three patients for whom complete PVI was not achieved, circumferential PV lesions were performed using approximately 20 seconds of RF applications to achieve greater than 90% reduction in electrogram amplitude and/or peak-to-peak and bipolar electrogram amplitude <0.1 mV, as end points. The mean total AF RFA time for these three patients was not statistically significant from the rest of the group (3638 ± 963 seconds for PVI vs. 3468 ± 453 seconds for circumferential ablation, $P = 0.64$).

AFL Characteristics

In this series of 20 patients with CTI-dependent AFL occurring immediately after LA ablation, the AFL was spontaneous in 4 patients (20%) and electrically induced by rapid atrial pacing in 16 patients (80%). The mean cycle length was 262.2 ± 28.5 ms (253.8 ± 9.5 ms for spontaneous and 264.3 ± 31.4 ms for induced, $P = 0.27$). CTI ablation with achievement of bidirectional block was performed in all subjects except one, whose procedure was terminated by cardioversion before an end point was recorded due to poor tolerance.

AFL Electrocardiographic Features

ECG features of the 20 patients with CTI-dependent AFL occurring during LA ablation for AF are summarized in Table 2. Three patients (15%) had typical AFL patterns and 17 patients (85%) had atypical flutter patterns. All patients with typical AFL ECG characteristics had CCW typical AFL characteristics, which were confirmed using right atrial electrograms recorded by a decapolar catheter (Fig. 1).

Overall, a biphasic pattern in the inferior leads II, III, and aVF was the most common inferior lead pattern (Fig. 2), present in 10 patients (50%). The next most common inferior lead flutter patterns were negative flutter waves in three patients (15%) (Fig. 3A) and predominance of positive flutter waves present in the inferior leads of three patients (15%) (Fig. 3B). Four patients (20%) had inferior lead flutter wave patterns that were not dominated by negative, positive, or biphasic waves. Among these 4 patients, the inferior lead flutter wave patterns were completely isoelectric in the first patient, predominantly isoelectric in the second, predominantly multicomponent (i.e., complex with multiple polarities) in the third (Fig. 4), and without a dominant inferior lead flutter wave pattern in the fourth patient. The patient with a prior history of AFL had biphasic flutter waves in the inferior leads.

In the precordial leads, the flutter waves in V_1 were positive in 14 patients (70%), isoelectric in 4 patients (20%), biphasic in 1 patient (5%), and negative in 1 patient (5%). The flutter waves in V_6 were negative in 8 patients (40%), isoelectric in 7 patients (35%), biphasic in 4 patients (20%), and uninterpretable in 1 patient (5%). No patient had positive flutter waves in V_6 . In the limb leads, the

Table 2. Electrocardiographic Features of Atrial Flutter

Patient	AFL	I	II	III	aVR	aVL	aVF	V ₁	V ₂	V ₃	V ₄	V ₅	V ₆	Pattern of inferior leads (i.e., leads II, III, aVF)
1	T	=	-	-	+	=	-	+	+	+	±	NA	±	Negative
2	A	=	±	-	±	=	=	+	+	=	=	=	=	Others, no pattern
3	A	=	±	±	±	±	±	+	=	-	-	-	-	Biphasic
4	A	=	-	±	±	-	±	+	+	±	-	-	-	Biphasic dominant
5	A	=	-	±	+	=	±	+	±	-	-	-	-	Biphasic dominant
6	A	=	=	±	=	=	=	+	+	=	NA	=	=	Others, isoelectric dominant
7	A	±	-	±	±	±	±	+	=	+	=	=	-	Biphasic dominant
8	A	+	+	±	=	±	+	=	=	=	=	=	=	Positive dominant
9	A	±	±	±	±	=	±	-	=	=	=	±	±	Biphasic
10	A	±	±	±	±	=	±	+	±	±	=	±	±	Biphasic
11	T	=	-	=	±	=	-	+	+	+	=	=	=	Negative dominant
12	A	=	±	+	+	-	±	±	±	+	±	-	-	Biphasic dominant
13	A	=	±	+	-	-	±	+	+	±	+	+	±	Biphasic dominant
14	A	=	±	±	-	-	±	+	+	+	=	=	-	Biphasic
15	A	=	=	m	=	+	m	=	=	=	=	=	=	Others, complex dominant
16	T	=	-	±	=	=	-	+	+	+	=	-	-	Negative dominant
17	A	±	±	±	±	-	±	+	=	±	±	-	-	Biphasic
18	A	=	=	=	=	=	=	=	=	=	=	=	=	Others, isoelectric
19	A	=	+	+	±	-	+	+	+	±	+	+	=	Positive
20	A	±	+	+	+	-	+	+	+	+	+	+	NA	Positive

T = typical atrial flutter pattern; A = atypical atrial flutter pattern; NA = not available.

Grading of flutter waves: = for isoelectric; ± for biphasic; + for positive; - for negative; m for complex flutter wave morphology with multiple components. Dominant = occurring in at least 2/3 of the inferior leads.

majority of patients had ECGs that were isoelectric in lead I and predominantly isoelectric in aVL. In lead I, the flutter waves were isoelectric in 14 of 20 patients (70%), biphasic in 5 (25%), and positive in 1 (5%). In lead aVL, the flutter waves were isoelectric

in 9 (45%), negative in 7 (35%), biphasic in 3 (15%), and positive in 1 (5%).

All four patients whose CTI-dependent AFL developed spontaneously after LA ablation had biphasic or biphasic-dominant (i.e., existing in at least 2/3

Figure 1. Intracardiac electrogram of typical, counterclockwise (CCW), cavotricuspid isthmus-dependent right atrial flutter (AFL). Lasso and coronary sinus (CS) electrograms are labeled in a distal-to-proximal fashion from 1 to 10 (Lasso) and 1 to 8 (CS). All isthmus-dependent AFLs proceeded in a CCW fashion.

Figure 2. Electrocardiogram revealing an atrial flutter EKG pattern with biphasic F-waves in the inferior leads. A biphasic inferior lead pattern was the dominant pattern observed, occurring in 50% of patients with CTI-dependent AFL occurring immediately after left atrial ablation.

of inferior leads II, II, aVF) flutter pattern in the inferior ECG leads. In contrast, biphasic or biphasic-dominant flutter patterns were observed in only 38% ($n = 6$ patients) of the 16 patients whose AFL was induced after AF ablation.

DISCUSSION

Major Findings

One of the primary findings of this study is that right AFL occurring during LA ablation for AF can have atypical ECG patterns not characteristic of CCW or CW CTI-dependent AFL and still be associated with a CTI-dependent mechanism. These AFLs, though atypical in appearance by ECG, can be successfully treated with RF ablation in the CTI. In this series of patients undergoing LA ablation for AF, a majority (85%) of CTI-dependent right AFLs that developed during the AF ablation were atypical in appearance. This has important clinical implications, since while many post-AF ablation AFLs are due to LA macroreentrant circuits,⁷ CTI-dependent right-sided AFLs with atypical features can also develop during or after AF RFA.^{2,7,8} Furthermore, our series notes that the atypical ECG appearance of spontaneous or induced CTI-dependent AFLs can occur in patients with both paroxysmal and persistent AF. If ablation of such arrhythmias is pursued, early entrainment map-

ping at the CTI when RA AFL is suspected in order to localize circuits critical for arrhythmia propagation may expedite procedure time and increase ablation efficiency.

Atypical ECG Appearance of CTI-Dependent AFL

The "sawtooth" pattern of AFL waves in the inferior ECG leads II, III, and aVF is a common characteristic of isthmus-dependent AFL.⁹ The inferior leads characteristically display negative flutter waves in CCW isthmus-dependent AFL, and positive flutter waves in CW isthmus-dependent AFL.¹ Nevertheless, variation is known to exist in the ECG patterns for CTI-dependent AFLs, and prior studies have noted that AFL with variable or uncharacteristic ECGs can still be CTI-dependent.^{2,8,10-15} CTI-dependent AFL with atypical ECG appearances has been observed in patients who have undergone cardiac interventions for atrial arrhythmias (surgical^{10,14} or transcatheter^{2,8,13}) or for correction of congenital heart disease.¹¹ Similar to prior report of CTI-dependent AFL occurring at least several months after LA AF ablation,² we note atypical ECG patterns in the majority of our CTI-dependent AFL occurring during LA AF ablation. Specifically, 85% of our series of 20 patients had ECGs uncharacteristic of CTI-dependent AFL. We believe that a possible

Figure 3. Electrocardiogram with inferior leads manifesting: (A) Downward (negative separated by isoelectric intervals) F-waves and (B) Upright (positive separated by isoelectric intervals) F-waves.

mechanism for these changes may partly be due to the fact that ablation and/or acute inflammation of LA tissue may lead to a change in the contribution of the septal component of the LA septum to the ECG flutter waves, and thus alter their morphological characteristics. Chugh et al. note that the debulking effect of LA ablation can lead to reduction in LA mass and voltage, resulting in an attenuated negative component of inferior flutter waves.²

In terms of specific ECG lead features, negative flutter waves in the inferior leads II, III, and aVF are predominant in patients with CCW CTI-dependent AFLs who have not undergone AF ablation,⁹ while positive flutter waves have been reported to be the predominant inferior lead pattern at several months post-AF RFA (occurring in 60% of those patients), a difference postulated to occur secondary to a change in the LA contribution to

Figure 4. Electrocardiograms with other atypical flutter patterns included predominantly multicomponent, complex F-waves in the inferior leads.

ECG voltage after ablation for AF.² In this series, biphasic flutter waves were the predominant inferior lead pattern in 50% of patients for AFLs developing during LA AF ablation. For lead I, 70% of the lead I patterns in this series of patient with AFL during AF RFA were isoelectric, compared to 40% of patients at several months post-RFA and 67% of patients in a control group of CTI-dependent AFL patients without LA RFA.²

Several factors may explain these differences in the inferior and frontal leads. First, this ECG pattern variation may in part be due to the timing of development of AFL after AF RFA. While the debulking and remodeling effects of LA ablation have been postulated to result in marked LA voltage reduction and craniocaudal RA free wall activation (and therefore contribute to the appearance of positive flutter waves in inferior ECG leads), these debulking and remodeling effects may require weeks to months after LA RFA, and may serve to at least partly explain the observed discrepancies in inferior leads flutter patterns between our study and prior findings. In addition, different techniques used for AF ablation may also account for differences in observations. In this study, the end point for ablation in the majority of patients was PVI compared to prior studies where the AF ablation end point was circumferential LA ablation.² Such difference in techniques may result in different levels of LA debulking and may have different effects on atrial substrate and subsequent AFL pat-

terns. Further research is required to address these issues.

Features in the precordial leads can help with localization of the AFL to the right atrium in the setting of atypical inferior lead features. In lead V₁, typical, CCW CTI-dependent AFL and CTI-dependent AFL occurring after LA ablation for AF are classically characterized by a predominantly positive component in lead V₁.^{2,9} Similar to these results, in this series, a total of 90% of patients manifested a predominantly positive (70%) or isoelectric (20%) flutter wave in V₁. In addition, lead V₆ was never positive, a feature that may help to distinguish these right-sided AFLs with atypical features from left-sided AFLs, which often possess positive flutter waves throughout the precordium.¹⁶

Finally, all four patients who spontaneously developed CTI-dependent AFL after LA ablation manifested biphasic flutter waves in the inferior waves. Since this number of patients is small, future studies may help elucidate the relationship between AF, spontaneously developing AFL, and the significance of biphasic flutter waves in the inferior leads.

LIMITATIONS

This study is limited by the small sample size of patients with right atrial, CTI-dependent AFL during LA ablation. In addition, the ECG limb leads

were placed on the anterior upper arms and hips in the EP laboratory, which may differ from ECG lead position in patients not undergoing an electrophysiology study, potentially affecting the morphology of AFL waves in corresponding leads. All electrophysiology procedures were performed at a single tertiary-care academic center by a small number of operators, so conclusions may not be representative of the general population of post-RFA AF patients.

CLINICAL IMPLICATIONS

In patients who undergo AF RFA, right-sided AFL that develops during AF ablation can manifest ECG patterns not characteristic of CCW or CW CTI-dependent AFL, but can still be associated with a CTI-dependent mechanism. Atypical ECG patterns occurred in 85% of CTI-dependent AFL patients, and a biphasic ECG pattern in the inferior leads is a common feature, occurring in 50% of patients. Even when the ECG is not characteristic of CTI-dependent AFL, a strategy that includes early entrainment mapping at the CTI can increase diagnostic efficiency.

CONCLUSION

Patients with CTI-dependent AFL occurring during LA ablation can have atypical ECG patterns. Biphasic flutter waves in inferior leads are common ECG features. Entrainment mapping at the CTI may expedite diagnosis for patients with development of AFL during AF ablation, even when the ECG is not characteristic of CTI-dependent flutter.

Acknowledgment: *We thank Cecille Garcia, N.P. for her assistance with the chart review process. We also acknowledge the work of our statistical consultant, Robert S. Sciacca, Eng.Sc.D.*

REFERENCES

1. Saoudi N, Cosio F, Waldo A, et al. A classification of atrial flutter and regular atrial tachycardia according to electrophysiological mechanisms and anatomical bases; a statement from a Joint Expert Group from The Working Group of Arrhythmias of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. *Eur Heart J* 2001;22:1162-1182.
2. Chugh A, Latchamsetty R, Oral H, et al. Characteristics of cavotricuspid isthmus-dependent atrial flutter after left atrial ablation of atrial fibrillation. *Circulation* 2006;113:609-615.
3. Sanders P, Berenfeld O, Hocini M, et al. Spectral analysis identifies sites of high-frequency activity maintaining atrial fibrillation in humans. *Circulation* 2005;112:789-797.
4. Ouyang F, Bansch D, Ernst S, et al. Complete isolation of left atrium surrounding the pulmonary veins: New insights from the double-Lasso technique in paroxysmal atrial fibrillation. *Circulation* 2004;110:2090-2096.
5. Pappone C, Santinelli V, Manguso F, et al. Pulmonary vein denervation enhances long-term benefit after circumferential ablation for paroxysmal atrial fibrillation. *Circulation* 2004;109:327-334.
6. Pappone C, Rosanio S, Oreto G, et al. Circumferential radiofrequency ablation of pulmonary vein ostia: A new anatomic approach for curing atrial fibrillation. *Circulation* 2000;102:2619-2628.
7. Garan H. Atypical atrial flutter. *Heart Rhythm* 2008;5:618-621.
8. Scharf C, Veerareddy S, Ozaydin M, et al. Clinical significance of inducible atrial flutter during pulmonary vein isolation in patients with atrial fibrillation. *J Am Coll Cardiol* 2004;43:2057-2062.
9. Medi C, Kalman JM. Prediction of the atrial flutter circuit location from the surface electrocardiogram. *Europace* 2008;10:786-796.
10. Akar JG, Al-Chekakie MO, Hai A, et al. Surface electrocardiographic patterns and electrophysiologic characteristics of atrial flutter following modified radiofrequency MAZE procedures. *J Cardiovasc Electr* 2007;18:349-355.
11. Biviano A, Garan H, Hickey K, et al. Electrophysiologic characteristics of atrial tachyarrhythmias in patients with teralogy of Fallot and pulmonic stenosis: Importance of cavotricuspid isthmus ablation. *Circulation* 2006;114:II-703.
12. Bochoeyer A, Yang Y, Cheng J, et al. Surface electrocardiographic characteristics of right and left atrial flutter. *Circulation* 2003;108:60-66.
13. Chugh A, Oral H, Lemola K, et al. Prevalence, mechanisms, and clinical significance of macroreentrant atrial tachycardia during and following left atrial ablation for atrial fibrillation. *Heart Rhythm* 2005;2:464-471.
14. Magnano AR, Argenziano M, Dizon JM, et al. Mechanisms of atrial tachyarrhythmias following surgical atrial fibrillation ablation. *J Cardiovasc Electr* 2006;17:366-373.
15. Milliez P, Richardson AW, Obioha-Ngwu O, et al. Variable electrocardiographic characteristics of isthmus-dependent atrial flutter. *J Am Coll Cardiol* 2002;40:1125-1132.
16. Gerstenfeld EP, Dixit S, Bala R, et al. Surface electrocardiogram characteristics of atrial tachycardias occurring after pulmonary vein isolation. *Heart Rhythm* 2007;4:1136-1143.