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

Hiroaki Mano, Ichiro Watanabe, Yasuo Okumura, Koichi Nagashima, Kazumasa Sonoda, Sonoko Ashino, Kazuki Iso, Keiko Takahashi, Naoko Sasaki, Rikitake Kogawa, Masayoshi Kofune, Kimie Okubo, Toshiko Nakai and Atsushi Hirayama
Division of Cardiology, Department of Medicine, Nihon University School of Medicine

Background and Aim: Cavo-tricuspid isthmus (CTI)-dependent atrial flutter (AFL) can develop in patients who have undergone percutaneous catheter ablation for atrial fibrillation (AF) or during left atrial (LA) ablation for AF. The electrocardiographic (ECG) characteristics of CTI-dependent AFL during LA ablation have not been described in detail. The purpose of this study was to ascertain and describe the ECG features of CTI-dependent AFL occurring during percutaneous LA catheter ablation for AF.

Methods and Results: Of 72 patients underwent AF ablation at our institution between January 2011 and December 2012, 33 (45.8%) exhibited CTI-dependent AFL during ablation for AF. Of these 33 patients, 26 and 7 exhibited typical and atypical ECG patterns, respectively. Flutter waves in the inferior leads were biphasic in 5 patients and positive in 2.

Conclusions: CTI-dependent AFL during LA ablation for AF often exhibits atypical ECG characteristics. In patients in whom atrial flutter develops during LA ablation, entrainment mapping should be performed at the CTI even if the ECG is uncharacteristic of CTI-dependent AFL.

Key words: atrial flutter, twelve-lead ECG, atrial fibrillation, ablation

Introduction

Typical atrial flutter (AFL), also known as type 1 AFL or cavotricuspid isthmus (CTI)-dependent flutter, refers to a right atrial macroreentrant arrhythmia circuit that involves the CTI and rotates in a typical counterclockwise (CCW) or reverse typical clockwise (CW) direction around the tricuspid annulus, which is the anterior boundary of the circuit. Patients who have undergone percutaneous left atrial (LA) radiofrequency catheter ablation (RFA) for atrial fibrillation (AF) can develop CTI-dependent AFL. Electrocardiographic (ECG) characteristics of CTI-dependent AFL developing several months after LA ablation for AF have been reported. Only Chyou et al. have described ECG characteristics of CTI-dependent AFL occurring during the LA ablation session. Understanding of these characteristics may help guide diagnosis in patients in whom AFL develops during AF ablation. The purpose of this study was to ascertain and describe the ECG features of CTI-dependent right atrial AFL occurring during LA ablation for AF.

Patients and Methods

Patients

Study patients were identified from among 72 consecutive patients (61 men and 11 women; mean age 56 ± 13 years; paroxysmal AF: n = 23, persistent AF: n = 40, long lasting AF: n = 9) who underwent LA ablation of AF at Nihon University Itabashi Hospital between January 2011 and December 2012. Thirty-three (46%) of the 72 patients who underwent mapping and ablation of spontaneous or induced CTI-dependent AFL during LA ablation constituted the subjects of this study. AF was defined as beat-to-beat variability in cycle length, morphology and activation sequence, whereas AFL manifested as a regular cycle length, morphology and activation sequence. Patients in whom AFL lasting more than 5 minutes developed spontaneously or during induction maneuvers were included in the study. Patients who had undergone prior cardiac surgery or catheter ablation procedures were excluded from the study.

AF mapping and ablation

All patients underwent anticoagulation for at least 1 month before the ablation procedure, with a target INR between 2.0 and 3.0. Antiarrhythmic medications were stopped for at least five half-lives before the procedure. Electrophysiologic study and ablation were performed under conscious sedation achieved with propofol and fentanyl. Surface ECGs and endocardial electrograms were monitored and stored on a digital recording system (BARD Lab Systems Pro, Murray Hill, NJ, USA). Intracardiac electrograms were filtered...
from 30 to 250 Hz at a sweep speed of 100–200 mm/sec. The LA was accessed by transseptal puncture, and a heparin bolus was administered to achieve an activated clotting time target of >300 seconds. No CTI-dependent AFL induction was performed before PV, LA ablation. LA mapping was performed with a 4-mm irrigated-tip quadripolar catheter (Navistar Thermocool; Biosense Webster, Diamond Bar, CA, USA) and the CARTO 3 three-dimensional electroanatomic mapping system (Biosense Webster). Extended ipsilateral pulmonary vein isolation (PV1) was performed under the guidance of two circumferential decapolar mapping catheters (Lasso, Biosense Webster) placed at the ipsilateral superior and inferior PVs. In addition, a deflectable octapolar catheter was positioned within the coronary sinus (CS). For PV1, continuous circular lesions were created around the ipsilateral PVs\(^5,6\). RFA was performed with an output power of 20–35 W and maximum catheter-tip temperature of 43°C. If AF was not terminated by PV1 or if AF lasting more than 5 minutes was inducible by rapid atrial pacing after PV1, complex fractionated atrial electrogram ablation\(^7\) in the LA and/or LA linear ablation\(^8\) was added. If AF was not terminated, cardioversion was performed.

**AFL induction and mapping**

If sinus rhythm was shown to be the underlying rhythm after RFA for AF was completed, programmed cardiac stimulation was performed from the LA appendage and CS ostium at decremental cycle lengths until 1:1 atrial capture was lost or a pacing cycle length of 200 ms was reached. When AFL characterized by a constant cycle length was induced or if the underlying cardiac rhythm after AF ablation transformed from AF to AFL with a stable cycle length, atrial electrograms were analyzed for the CS sequence. If a proximal-to-distal CS activation sequence was seen, a duo-decapolar ring catheter (Halo, Biosense Webster) was placed along the tricuspid annulus (TA). If the activation sequence around the TA was consistent with isthmus-dependent right atrial 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 the atrial rate to the pacing rate with identical P wave morphologies and activation sequences from the right atrial duo-decapolar catheter and CS catheters, and the postspacing interval (PPI) minus AFL cycle length was ≤30 ms, the pacing site was deemed to be located in the circuit of the reentrant tachycardia. This was defined as CTI-dependent AFL. AFL ablation was performed in the CTI at a power setting of 35–40 W with a 4-mm irrigated-tip catheter. The endpoint of the procedure was the presence of bidirectional block in the CTI during pacing from the CS ostium and from the lateral CTI.

**ECG analysis**

Twelve-lead ECGs of all the CTI-dependent AFLs were analyzed by two investigators (H.M., Y.O.); a third investigator (I.W.) adjudicated discrepancies. The AFL ECG patterns were classified overall as typical if either right atrial CTI CCW or CW ECG features were present.\(^7\) That is, typical CCW AFL was defined as characteristic negative sawtooth flutter waves that predominated in the inferior leads and a positive component in lead V1 that became inverted or isoelectric by lead V6. Reverse typical CW AFL was defined as characteristic positive sawtooth flutter waves that predominated in the inferior leads and a negative component in lead V1 that transitioned to positive by V6. If neither of these two patterns was present, the ECGs were classified as atypical in appearance. Polarity of the AFL waves in each lead was 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 mixed (i.e., complex with multiple polarities).\(^7\) Prevalence of atypical AFL ECG in the inferior limb leads between patients categorized by the positive, negative versus biphasic, mixed.

**Statistical Analysis**

Continuous variable (age) is presented as mean ± SD and categorical variables (sex, type of AF, and ablation procedure type) as percentages. Differences in continuous variables were analyzed by Mann-Whitney U test, and differences in categorical variables were analyzed by Fisher’s exact probability test or Friedman test. A p value of < 0.05 was considered statistically significant. Statistical analyses were performed with the use of StatView 5.0 software (SAS Institute, Cary, NC, USA).

**Results**

Among the 72 AF patients, extensive encircling PV1 (EEPVI) was performed in 41 (57.0%), EEPVI + CFAE ablation was performed in 9 (12.5%), and EEPVI + CFAE ablation + LA linear ablation was performed in 22 (30.5%), and CTI-dependent AFL developed spontaneously or by rapid atrial pacing in 33 (45.8%), who became our study subjects. All 33 patients showed a CCW TA activation pattern. Twenty-six of these 33 patients (78.8%; male/female ratio, 23/3; age, 61 ± 9 years; paroxysmal AF: n = 15, persistent AF: n = 10, long lasting AF: n = 1) showed typical negative P wave polarity in the inferior leads. EEPVI was performed in 17 of these 26
patients, EEPVI + CFAE ablation was performed in 3 patients, and EEPVI + CFAE ablation + LA linear ablation was performed in 6 patients. The remaining 7 patients (21.2%; male/female ratio: 5/2; age: 57 ± 9 years; paroxysmal AF: n = 3, persistent AF: n = 3, long lasting AF: n = 1) had an atypical ECG pattern/polarity in the inferior leads—2 with a positive P wave and 5 with a biphasic P wave. EEPVI was performed in 4 patients and EEPVI + CFAE ablation + LA linear ablation in 3 patients. The prevalence of atypical AFL ECG patterns did not differ significantly according to sex (p = 0.281) and age (p = 0.354). The prevalence of atypical AFL ECG patterns in the inferior limb leads among the 33 patients in whom CTI-dependent AFL developed did not differ between paroxysmal AF (3/15) and non-paroxysmal (persistent AF + long lasting AF, 4/11, p = 0.210) patients or between EEPVI-only patients (4/17) and EEPVI + CFAE ablation/EEPVI + CFAE ablation + LA linear ablation patients (3/9, p = 0.198).

Case presentation

**Case 1.** The patient was a 66-year-old man with long-lasting AF who underwent EEPVI + CFAE ablation + LA linear ablation. AFL developed spontaneously during LA linear ablation, and entrainment pacing from the CTI showed a post-pacing interval PPI–tachycardia cycle length of -2 ms (Fig. 1, right). Therefore, this AFL proved to be CTI-dependent CCW AFL. Twelve-lead ECG during AFL revealed a positive P wave in the inferior leads (Fig. 1, left).

**Case 2.** The patient was a 50-year-old man with paroxysmal AF who underwent EEPVI. AFL was induced by rapid atrial pacing from the CS ostium after EEPVI, and entrainment pacing from the CTI showed a PPI–tachycardia cycle length of 2 ms (Fig. 2, right). Therefore, this AFL proved to be CTI-dependent CCW AFL. Twelve-lead ECG during AFL showed a biphasic (-/+1) P wave in the inferior leads (Fig. 2, left).

**Case 3.** The patient was a 48-year-old woman with paroxysmal AF who underwent EEPVI + CFAE ablation + LA linear ablation. AFL developed spontaneously during LA linear ablation, and entrainment pacing from the CTI showed PPI–tachycardia cycle length of 2 ms (Fig. 3, right). Therefore, this AFL proved to be CTI-dependent CCW AFL. Twelve-lead ECG during AFL showed a biphasic (-/+1) P wave in the inferior leads (Fig. 3, left).
Fig. 2  Left Panel: Surface electrogram of the tachycardia in Case 2. The tachycardia (marked by the arrows) polarity of the inferior limb leads was biphasic (-/+/). Right panel: Simultaneous recordings from the surface ECG (leads II and V1), high right atrium (HRA), His bundle electrogram recording site (HBE), duo-decapolar catheter along the tricuspid annulus (TA) with its distal electrode (TA1-2) located at the inferolateral TA and proximal (TA19-20) close to the high septal TA (tachycardia cycle length = 260 ms), and coronary sinus (CS) catheter. The counterclockwise activation patterns along the TA and proximal-to-distal coronary sinus activations are marked by the arrows. Note that pacing from inferolateral TA (TA1-2) at a cycle length of 250 ms showed post-pacing interval–tachycardia cycle length of 2 ms, therefore, this tachycardia proved to be cavo-tricuspid isthmus-dependent clockwise atrial flutter. S: stimulus artifact.

Fig. 3  Left Panel: Surface electrogram of the tachycardia in Case 2. The tachycardia (marked by the arrows) polarity of the inferior limb leads was biphasic (-/+/). Right panel: Simultaneous recordings from the surface ECG (leads II and V1), duo-decapolar catheter along the tricuspid annulus (TA) with its distal electrode (TA1-2) located at the inferolateral TA and proximal (TA19-20) close to the high septal TA (tachycardia cycle length = 198 ms), ablation catheter (ABL), and coronary sinus (CS) catheter. The counterclockwise activation patterns along the TA and proximal-to-distal coronary sinus activations are marked by the arrows. Note that pacing from inferolateral TA (TA1-2) at a cycle length of 180 ms showed post-pacing interval–tachycardia cycle length of 2 ms, therefore, this tachycardia proved to be cavo-tricuspid isthmus-dependent clockwise atrial flutter. S: stimulus artifact.
Ablation for AF

AFL can develop during or after radiofrequency ablation in patients who have undergone catheter ablation with an atypical ECG appearance has been observed in the inferior leads.

This has important clinical implications because, though many post-AF ablation AFLs are due to LA macroreentrant circuits, right-sided CTI-dependent AFL can develop during or after radiofrequency ablation for AF. Chugh et al. reported that 15 of 65 patients (23%) of their postablation AFLs were characterized by positive P waves in the inferior leads. Furthermore, Chyou et al. reported that 9% of patients developed CTI-dependent AFL during LA ablation for AF, and 85% of the CTI-dependent CCW AFLs showed atypical ECG patterns: 50% with biphasic flutter waves, 15% with positive flutter waves and 15% with unclassified flutter waves in the inferior leads. The difference in the prevalence of atypical ECG patterns between the Chyou et al. patient series and our patient series may be explained in part by the difference in the prevalence of CTI-dependent AFL (9% vs. 46%).

Major findings

One of the primary findings of this study is that right AFL occurring during LA ablation for AF can have ECG patterns uncharacteristic of CCW or CW CTI-dependent AFL and still have an underlying CTI-dependent mechanism. These AFLs, though atypical in ECG appearance, can be successfully treated by RF ablation in the CTI. In our series of patients undergoing LA ablation for AF, 21% of the CTI-dependent right AFLs that developed during the AF ablation procedure were atypical in appearance. It may be that ablation and/or acute inflammation of the inferior flutter waves without a change in the activation sequence within the right atrium. Therefore, changes in the LA activation sequence produced by LA ablation might affect the surface ECG morphology of CTI-dependent AFL.

Discussion

Atypical ECG appearance of CTI-dependent AFL

The sawtooth pattern of flutter waves in inferior ECG leads II, III and aVF is a common characteristic of right atrial isthmus-dependent AFL. The inferior leads characteristically display negative flutter waves in CCW isthmus-dependent AFL and positive flutter waves in CW isthmus-dependent AFL. Nevertheless, variation is known to exist in the ECG pattern for CTI-dependent AFLs, and prior studies have shown that AFL with variable or uncharacteristic ECGs can still be CTI-dependent. CTI-dependent AFL with an atypical ECG appearance has been observed in patients who have undergone catheter ablation. We noted atypical ECG patterns in 21% of CTI-dependent AFLs that occurred during LA AF ablation. It may be that ablation and/or acute inflammation of LA tissue leads to a change in the contribution of the atrial septum and LA to the ECG flutter waves and thus alters their morphologic characteristics. Chugh et al. noted that the debulking effect of LA ablation can lead to a reduction in LA mass and voltage, resulting in attenuation of the negative component of the inferior flutter waves. We showed previously that impulse conduction to the left atrial free wall through either lower or upper interatrial connection is a major determinant of ECG atrial free wall inpatients undergoing an electrophysiology study, which may differ from ECG lead positions in patients not undergoing an electrophysiology study, potentially affecting the morphology of AFL waves in corresponding leads.

Clinical implications

Patients with CTI-dependent AFL occurring during LA circumferential ablation can show atypical ECG patterns. Even when the ECG is not characteristic of CTI-dependent flutter, 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. Entrainment mapping at the CTI may expedite diagnosis for patients in whom AFL develops during AF ablation, even when the ECG is not characteristic of CTI-dependent AFL.

References


