Usefulness of the Noncontact Mapping System to Elucidate the Conduction Property for the Treatment of Common Atrial Flutter

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Background: *The functional role of the cavotricuspid isthmus (CTI) for common atrial flutter (cAFL) remains to be elucidated. In the present study, we examined whether the EnSite system (St. Jude Medical, St. Paul, MN, USA), a noncontact mapping system, is useful to evaluate the conduction properties of CTI to minimize radiofrequency (RF) ablation applications for cAFL.*

Methods: *We enrolled 22 consecutive patients with cAFL (64.1 ± 9.5 years old, M/F 21/1) treated with the EnSite system and examined the conduction properties during cAFL and during atrial pacing. In addition, the effectiveness of the system was evaluated in comparison with the conventional ablation group (67 ± 8.9 years old, n = 15, M/F 13/2).*

Result: *In 11 out of the 22 patients, CTI block line was achieved by fewer RF applications on a presumed single activation pathway which the EnSite system showed (point ablation [PA] group), and the remaining 11 patients needed additional linear ablation (additional ablation [AA] group). The number of RF applications in the PA group was significantly smaller than that in the conventional group. During the lower lateral right atrial pacing at a cycle length of 600 ms, the CV of the CTI in the PA group was smaller compared to that in the AA group (1.36 ± 0.61 vs 2.17 ± 0.66 m/s, $P < 0.05$), although the CV during cAFL (averaged cycle length 245 ± 34 ms) was not different in both groups.*

Conclusions: *These results indicate that targeting the presumed single line identified by EnSite could be an optional therapy for cAFL RF ablation, and diverse conduction properties in CTI are related to the success rate of this procedure. (PACE 2012;35:1464–1471)*

noncontact mapping, catheter ablation, common atrial flutter, cavotricusupid isthmus, conduction velocity

Introduction

Treatment of common atrial flutter (cAFL) with radiofrequency (RF) ablation to the cavotricuspid isthmus (CTI) is well-established and is the first-line therapy.[1,2] Conventionally, RF ablation of the CTI, with complete bidirectional conduction block, is a highly effective treatment for this arrhythmia.[3–5] Although the CTI is the most important ablation site for cAFL, the anatomic features of the CTI are complicated and the conduction properties in the CTI remain to be elucidated.[6,7] The CTI is composed of a series of distinct anatomically defined muscular bundles that are usually separated by small or large visible gaps of intervening connective tissue.[8] The anatomic linear ablation of the CTI may not be essential to establish the block line of cAFL circuit, although this strategy has been conventionally performed. It has been reported that the mapping-guided ablation of the CTI may be useful with a resultant smaller number of RF applications compared with the conventional linear CTI ablation.[9–11] The target of this technique is the high-amplitude atrial electrograms on the CTI, but it does not refer to the conduction properties of the entire CTI. In addition, it is unclear which patients with cAFL are suitable for this technique.

The identification of the critical pathway on CTI during cAFL might lead to the establishment of a less invasive RF therapy for cAFL. Conventional mapping techniques, however, are insufficient to examine the propagation pattern because of the various anatomical muscular bundles on CTI. Recently, 3D mapping systems have been developed to improve the mapping accuracy and efficacy of RF treatment. Especially, the 3D mapping system using a multielectrode array (EnSite, EnSite 3000 with Precision

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Software Endocardial Solutions, St. Jude Medical, St. Paul, MN, USA) is able to reveal the excitation movement of cardiac muscle,[12–16] which is supposed to express the conduction pathway. Thus, the aim of the present study was to examine whether the EnSite system is useful to elucidate the characteristics of the CTI conduction leading to minimized RF applications for cAFL.

Methods

The present study was approved by the ethical committee of Tohoku University Graduate School of Medicine. Informed written consent was obtained from all patients prior to the procedures.

Study Populations

We enrolled 22 consecutive patients with documented cAFL in 12-lead electrocardiogram who were referred for RF ablation (21 males and one female, mean age, 64.1 $\pm$ 9.5 years old). We excluded patients with decompensated heart failure, intolerance for prolonged immobility, and high risk of thromboembolism during noncontact mapping. Among the 22 patients, five had a past history of heart failure and 12 of hypertension. In addition, we included 15 consecutive control patients with cAFL who had met the enrollment criteria in the present study, and had previously undergone conventional linear ablation with the same radiofrequency catheter ablation (RFCA) devices as in the present study. The diagnosis of CTI-dependent atrial flutter was confirmed by the atrial activation sequence and concealed entrainment mapping during the RF ablation procedure.

Electrophysiological Study

All antiarrhythmic drugs were discontinued for at least five half-lives before the study. All patients were studied under nonsedated state. A 7-F, 20-pole, deflectable catheter with 2-10-2-mm spacing was positioned around the tricuspid annulus to simultaneously record the right atrial activation in the lateral wall and the CTI, and a 5-F, 8-pole, deflectable catheter was positioned around the His bundle via the right femoral vein. A 5-F, 10-pole, deflectable catheter was inserted into the coronary sinus (CS) via the right subclavian vein, and the proximal electrode pairs were placed at the ostium of the CS. A 9-F sheath was placed in the left femoral vein to introduce a noncontact EnSite mapping catheter. Heparin was given as a bolus injection to maintain an activated clotting time between 200 and 300 seconds throughout the electrophysiological study and RF catheter ablation. The noncontact mapping system (EnSite 3000 with Precision Soft ware Endocardial Solutions) has been described in detail previously.[17] The EnSite system consists of a noncontact catheter (9F) with a multielectrode array (MEA) surrounding a 7.5-mL balloon mounted at the distal end. The MEA catheter was deployed toward the tricuspid annulus over a 0.035-inch guide wire, which had been advanced to the pulmonary outflow tract. The system was capable of locating any catheter in relation to the MEA in the right atrium, and a locator signal gathered by the catheter was used to construct a 3D computer model of the virtual endocardium. Geometric points were sampled at the beginning of this study during sinus rhythm or cAFL. We examined the CTI conduction properties with the EnSite noncontact mapping system during both AFL and sinus rhythm performing atrial pacing protocols with a 600-ms cycle length from the coronary sinus ostium (CSos) and lower lateral right atrium (LLRA). We terminated atrial flutter with electrical cardioversion and induced it by atrial burst pacing at the CSos.

Radiofrequency Catheter Ablation

All 22 patients underwent RF catheter ablation procedure guided by the EnSite system, which enabled us to identify the unipolar maximum voltage area along the electrical activation pathway in the CTI during cAFL and/or pacing from the CSos or LLRA. Mapping of the CTI, LLRA, or lower septal right arium (LSRA) was performed during AFL and atrial pacing from CSos or LLRA. RF ablation was performed by point-by-point approach instead of dragging. An 8-mm-tip catheter (Ablaze, Lifeline Inc., Tokyo, Japan) was used with the maximum power 50 W and the maximum temperature 50°C. RF application was delivered for 40–60 seconds at each application point and was continued for up to 120 seconds when a bidirectional block along the CTI was achieved. First of all, we identified a presumable single pathway in the CTI using activation mapping with the EnSite system (Fig. 1). RF energy was delivered at the high-voltage points along the pathway until a bidirectional block line in the CTI (point ablation [PA] group) or the disappearance of the high-voltage area in the pathway was achieved. When we failed to achieve a block line by the ablation of the single pathway, we then performed additional linear ablation (additional ablation [AA] group). In this AA group, the RF energy was anatomically delivered to the persisting potential in the CTI linear line from the tricuspid annulus to the inferior vena cava. The procedural endpoint was a bidirectional block along the CTI. Clockwise and counterclockwise conduction blocks were confirmed with the splitting of the local atrial potential in the CTI and different pacing methods.[18] Successful bidirectional block

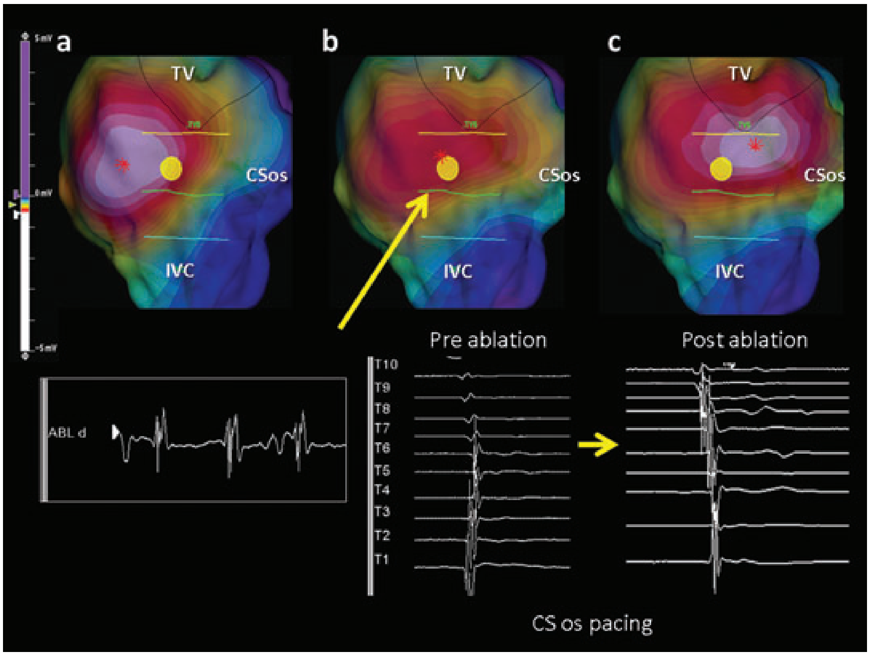

Figure 1. *Catheter ablation using the EnSite system. The propagation map during common atrial flutter (cAFL) is shown in the upper panel, where the activation wavefront traveled through the left lower right atrium (LLRA) to the coronary sinus ostium (CSos) in the cavotricuspid isthmus CTI (a, b, and c). The yellow tags show the ablation points. In these points, high-voltage potential was recorded (lower left panel). The activation sequence in the LLRA wall changed after the achievement of CTI block line (lower right panel). In this case, we were able to create a complete CTI block line by only one point ablation. TV = tricuspid valve; IVC = the inferior vena cava.*

was confirmed at 30 minutes after the final RF application in all patients.

Examining the CTI Conduction Property

As mentioned above, the CTI, LLRA, and LSRA conduction velocities were measured during cAFL and/or pacing at the CSos or LLRA (600-ms pacing cycle length). We then compared the conduction properties of the PA group, where we needed fewer RF applications only at the maximal potential sites along the presumable single pathway shown by the EnSite system, with the AA group, where we needed to perform additional RF applications to the entire CTI between the tricuspid annulus and the inferior vena cava after the failure of point ablation procedure.

To examine the properties of electrical activation pathway in the CTI, three lines were set in the CTI as follows: the side of tricuspid valve, the center of the CTI, and the side of the inferior vena cava and the averaged data were evaluated to reduce the influence of the different direction. The EnSite mapping system, by displaying the Cartesian coordinates relative to the MEA center of points on the virtual endocardium, enabled us to calculate the distance between the two points mathematically.[19] Each line was set to 20 mm long. The wavefront on the isopotential map was observed as the propagation of the peak negative point. The conduction time on the each line was determined as the time interval of the peak negative point between both ends of the line. The conduction velocity (CV) was calculated as the distance divided by the conduction time.

Statistical Analysis

Continuous data were expressed as the mean ± standard deviation (SD). Continuous variables were compared by Student's *t*-test, and one way analysis of variance (ANOVA) was used for multiple comparisons. The X^2 test was used to analyze the qualitative data. Nonparametric tests were used to compare continuous variables if there was a nonnormal distribution. A P-value of <0.05 was considered statistically significant.

Results

Catheter Ablation

The patient characteristics are shown in Table I. There were no significant differences in

Table I.

Clinical Characteristics of the Three Groups

	PA Group (n = 11)	AA Group (n = 11)	Control Group (n = 15)	P Value
Male/Female	10/1	12/0	13/2	n.s.
Age (years old)	66.4 ± 8.9	61.8 ± 9.6	67.0 ± 8.9	n.s.
Past History (n,%)				
SHD	5 (45.4)	3 (27.3)	2 (13.3)	n.s.
AF	8 (72.7)	7 (63.6)	11 (73.3)	n.s.
HT	5 (45.4)	7 (63.6)	9 (60.0)	n.s.
CHF	2 (18.1)	3 (27.3)	5 (33.3)	n.s.
Stroke	2 (18.1)	2 (18.2)	1 (6.6)	n.s.
UCG				
LAD (mm)	37.5 ± 5.3	35.4 ± 5.9	35.6 ± 5.7	n.s.
FS	0.35 ± 0.09	0.37 ± 0.06	0.36 ± 0.11	n.s.
BNP (pg/mL)	67.2 ± 59.4	56.6 ± 43.8	130.8 ± 162.2	n.s.
AFL-CL (ms)	249.2 ± 40.8	242.1 ± 31.4	227.6 ± 37.3	n.s.

Results are expressed as mean ± SD.
PA = point ablation; AA = additional ablation; SHD = structure heart diseases, including ischemic heart disease in one, hypertensive heart disease (HHD) in three, valvular heart disease in one in the PA group; and HHD in three, tachycardia-induced cardiomyopathy in one, and hemodialysis in one in the AA group. AF = atrial fibrillation; HT = hypertension; CHF = congestive heart failure; UCG = ultrasound cardiography; LAD = left atrium dimension; FS = fractional shortening; BNP = brain natriuretic peptide; AFL-CL = cycle length of the atrial flutter.

age, sex, structural heart diseases, past history, UCG parameters, serum BNP level, and cycle length of cAFL among the three groups. The presence of CTI-dependent atrial flutter was confirmed by the atrial activation sequence and concealed entrainment mapping during the RF ablation procedure. We were able to create a complete CTI block line in all patients. There were 11 patients where RF energy was only applied at the maximal potential sites on the presumable

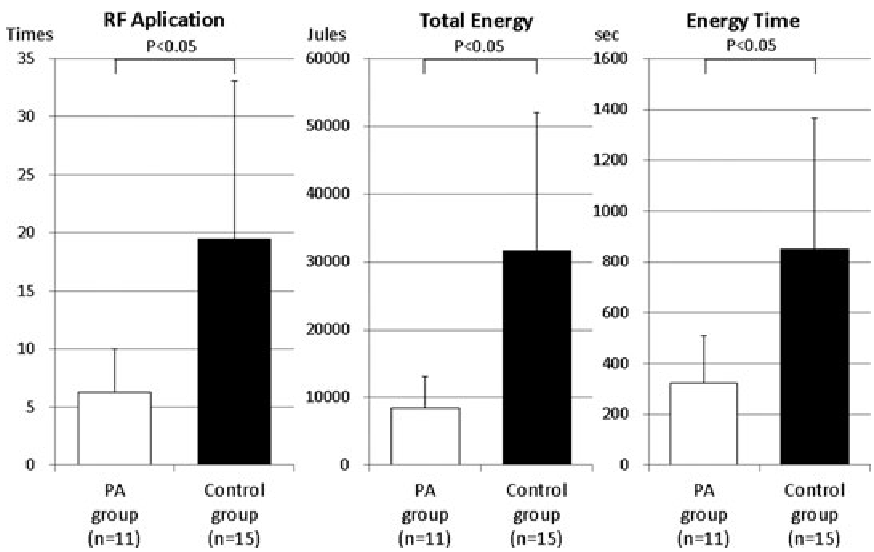

Figure 2. *Comparison between the point ablation and the conventional ablation. The point ablation (PA) group significantly needed a smaller number of radiofrequency applications, total energy, and energy time to complete a CTI block line as compared with the conventional linear ablation group (control group).*

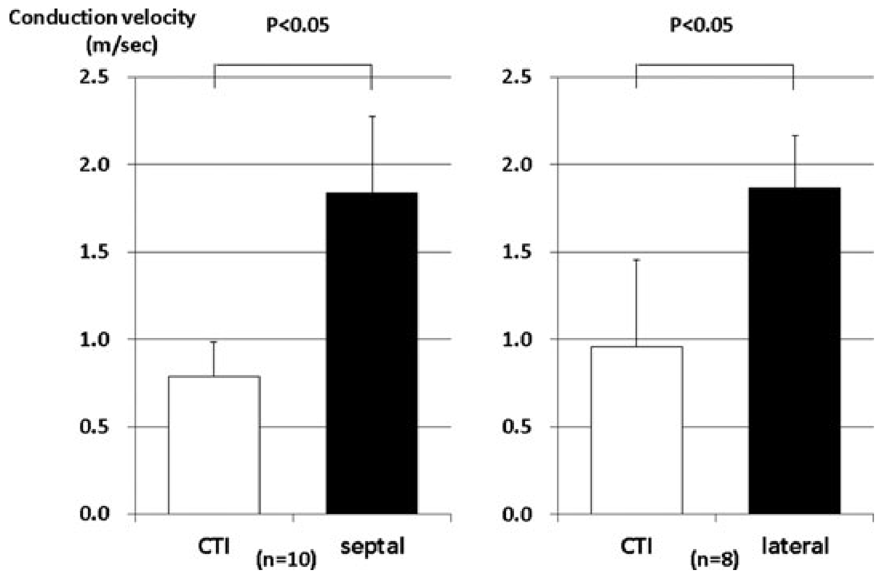

Figure 3. *The conduction velocity in the cavotricuspid isthmus, lower lateral right atrium, and lower septal right atrium during common atrial flutter. The conduction velocity in cavotricuspid isthmus (CTI) was significantly slower than those in lower lateral right atrium (LLRA), or lower septal right atrium (LSRA) during common atrial flutter. Abbreviations are the same as in Fig. 1.*

single pathway (PA group) (Fig. 1). The PA group needed a significantly smaller number of RF applications and less energy to complete a CTI block line compared with the control ablation group (conventional linear ablation) (Fig. 2). On the other hand, the remaining 11 patients, after failure of the point ablation, needed additional RF applications over the single pathway to create a complete block line (AA group). There were no differences between the AA group and the control group as regards RF applications, total energy, and energy time (RF application; 19.2 ± 10.0 vs 19.5 ± 13.6, total energy; 25152.0 ± 23195.8 vs 31657 ± 20431.7, energy time; 771.1 ± 290.4 vs 848.9 ± 516.5, n.s.).

Conduction Properties of the Cavo-Tricuspid Isthmus

We measured and averaged the conduction velocities of the three lines in the CTI: the side of the tricuspid annulus, the center of the CTI, and the side of the inferior vena cava, and also measured the CV at the LLRA or LSRA. The averaged CV was significantly slower in the CTI (0.96 ± 0.38 m/s) than that in the LLRA (1.84 ± 0.43 m/s) or LSRA (1.87 ± 0.30 m/s) during cAFL (Fig. 3). Furthermore, the CV was significantly slower in the PA group than in the AA group during LLRA pacing, and a similar tendency was noted during CSos pacing (LLRA 1.36 ± 0.61 vs 2.17 ± 0.66, $P < 0.05$; CSos 1.39 ± 0.48 vs 1.97 ± 0.75, $P = 0.06$), although the CV was comparable between the two groups during cAFL (Fig. 4).

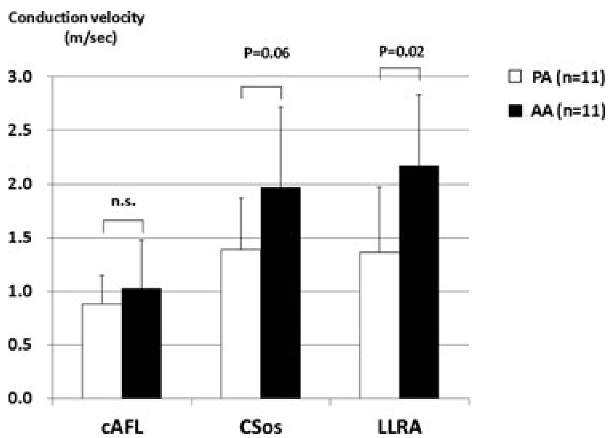

Figure 4. *Comparison of conduction velocity between point ablation and additional ablation. In the point ablation (PA) group, conduction velocity ratio during LLRA pacing was significantly smaller than the additional ablation (AA) group; a similar tendency was found during CSos pacing, although the conduction velocity during cAFL was comparable between the two groups.*

Follow-Up after Catheter Ablation

All patients were discharged after successful catheter ablation without major complications.

The average follow-up period was 195.4 ± 294.4 (range 5–1,072, median 28) days. There was cAFL recurrence in two cases in the PA group and none in the AA group (P = 0.24).

Discussion

In the present study, complete CTI block line with point ablation strategy was achieved in half of the patients and they needed a significantly smaller number of RF applications and less energy as compared with the conventional linear ablation group. The CV during LLRA or CSos pacing in the PA group was smaller than that in the AA group which required additional RF applications due to unsuccessful point ablation, although there was no difference of the CV during cAFL in both groups. The EnSite, noncontact mapping system was useful to visualize the presumable pathways on the CTI during cAFL where there are diverse conduction properties related to the results of RF catheter ablation.

Cavo-Tricuspid Isthmus as a Crucial Area in Common AFL Circuit

The cavo-tricuspid isthmus (CTI) between the inferior vena cava and the tricuspid annulus is (the main target for cAFL ablation procedures) an important region for cAFL procedures.[4,5] The conduction velocity in the CTI is slower than that in other areas during cAFL[7,20] or pacing,[21] indicating that the CTI is a critical area representing the slow conduction region in the re-entrant tachycardia circuit. Tai et al. reported that the incremental pacing cycle length at the LLRA or CSos between 250 and 500 ms delays CV in the CTI, but not the CV of the free wall, and furthermore gradual conduction delay with uni-directional block in the CTI leads to the initiation of cAFL.[22] These results indicate that the characteristics of slow or decremental conduction in the CTI are closely associated with maintenance and/or initiation of cAFL. In the present study, the CV during cAFL was slower in the CTI than that in the LLRA or LSRA. This finding supports the notion that the CTI could be an important slow conduction area for cAFL circuit.

The Anatomy of the CTI for Point Ablation

The CTI morphology is quite variable. Previous studies with CTI autopsy specimens demonstrated that the majority of bundle architecture was characterized by small or large visible gaps of intervening connective tissue, whereas the continuous homogenous atrial tissue was the minority.[6,8] These results imply that the distribution of muscle bundles in the CTI is considerably heterogeneous, which may be an important point for the procedure of CTI ablation. Based on this notion, a voltage-guided point ablation technique has recently been developed as a new approach for cAFL treatment, as compared to the conventional linear ablation of the CTI as an established technique for cAFL. The former targets only high-voltage points without making a linear ablation line to achieve CTI block line. Redfearn et al. demonstrated that a voltage-guided PA is useful to achieve a CTI block line without a complete anatomical line.[23] In addition, this ablation method is a feasible technique to reduce ablation time and application number of RFCA compared with conventional linear ablation.[24,25] The point ablation strategy in the present study, through the need of fewer RF applications, might open the way to a less invasive strategy in the future as compared to conventional linear ablation.

On the other hand, there are some difficult cases for making a block line, as thickened bundle and wide CTI region could influence the ablation procedure.[26,27] In the present study, approximately half of the patients required additional linear ablation after the PA therapy. The present success rate with the PA therapy was lower than in the previous studies, probably because the present PA procedure was limited to only one bundle pathway that the EnSite system revealed, whereas previous studies targeted multiple bundles.[23,25] However, the present results provide important information to elucidate the CTI anatomy. The CV of CSos or LLRA pacing was greater in the AA group than in the PA group, although the relatively slower CV during cAFL was comparable between the PA and the AA groups. This might mean that a main bundle with slow conduction is used as the slow conduction zone of reentry circuit during cAFL, and there are multiple bystander bundles in addition to the main bundle of cAFL circuit in the AA group, although there may be only one main bundle or few bystander bundles in the CTI in the PA group. Thus, the evaluation of the CV in the CTI is useful for understanding the CTI anatomy and thus making appropriate strategy for cAFL treatment.

The CTI Ablation Using Electro-Anatomical Mapping System

Electro-anatomical mapping system (EAMS) is useful to understand complicated mechanisms of various tachyarrhythmias. Application of EAMS to cAFL reveals the characteristics of the CTI and leads to less invasive procedures.[24,28] The EnSite system (noncontact EAMS) that we used in the present study is also useful to evaluate the conduction properties of atrial tachyarrhythmias. Liu et al. reported the functional role of the crista terminalis in patients with atrial flutter using the

EnSite system.[19] Chen et al. showed the slow conduction zones in the cAFL circuit with the EnSite system.[7] In the present study, the EnSite system also enabled us to visualize the conduction pathway and the maximal voltage area, thus demonstrating the "main" bundle involved during cAFL. In addition, the CV using closed virtual unipolar potentials on both ends can be calculated with this system. The data combined with these lines of information are helpful to establish an effective therapeutic strategy for cAFL.

Study Limitations

Several limitations should be mentioned for the present study. First, the lines that were determined for CV measurements by the EnSite system did not exactly reflect accurate directions of bundles in the CTI. Thus, the CV on the three lines in the CTI was measured and the conduction properties using the averaged data were evaluated to reduce the influence of the different directions. Second, since the number of patients in each group in this study was relatively small, further studies with a large number of patients are needed to confirm our findings in the present study. Third, the recurrence rate in the PA group was higher compared with previous studies.[2] Although a complete CTI block line was created successfully in all patients, more RF applications around the target bundle might have been needed for satisfactory long-term results. Further investigations are necessary to answer this problem. Fourth, the EnSite system is a more costly and complicated procedure for cAFL ablation compared with the conventional method. However, in terms of applied RF applications and energy, the point ablation strategy in the present study is less invasive compared with the conventional linear ablation.

Conclusions

There are diverse conduction properties in CTI, which might influence the results of RF catheter ablation. Half of the patients in the present study had successful ablation targeting the high-voltage area identified by EnSite system, resulting in fewer RF applications and less delivered energy. Localized ablation using this system could become an option for cAFL RFCA.

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