Novel method to evaluate the conduction velocity and conducting area during isthmus-dependent atrial flutter

İstmusa bağımlı atriyal flatter sırasında iletim hızı ve iletim alanının yeni bir yöntemle değerlendirilmesi

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ABSTRACT

Objective: The difference of the conduction velocity (CV) around the tricuspid valve annulus between the counter-clockwise (CCW) atrial flutter and the clockwise (CW) atrial flutter has not been well clarified. This study was undertaken to evaluate the CV and the conducting area (CA) per millisecond around the tricuspid valve annulus using the electroanatomical mapping.

Methods: The electroanatomical mapping was performed during the tachycardia for 30 consecutive patients (mean age: 61±16 years) with isthmus-dependent atrial flutter (CCW, 25; CW, 5). We measured the CV and the CA of five divided areas of the right atrium, that is, upper septum (US), lower septum (LS), isthmus (I), upper lateral wall (UL) and lower lateral wall (LL) using the novel measurement method in the isochronal map. Statistical differences of these data between the two groups were assessed by the Student's t-test and one-way analysis of variance methods.

Results: In total, the CV of the LS was significantly slower than other areas (m/sec: US, 0.57±0.18; LS, 0.43±0.18; UL, 0.60±0.26; LL, 0.53±0.20; I, 0.50±0.17; p<0.05) and the CA of the US and UL were significantly larger than other areas (mm^2/sec: US, 34.5±16.2; LS, 16.2±9.5; UL, 40.0±14.1; LL, 27.0±17.0; I, 16.8±8.5; p<0.0001). There was no significant difference between the CCW and the CW atrial flutters in terms of the CV and the CA of equally divided five areas.

Conclusion: In both of the CCW and the CW atrial flutters, the CV of the LS was significantly slower than other areas and the CA of the lower atrium was significantly smaller than the upper atrium. *(Anadolu Kardiyol Derg 2011; 11: 711-6)*

Key words: Atrial flutter, conduction velocity, conducting area, electroanatomical mapping system

ÖZET

Amaç: Tipik (CCW) ve ters tipik (CW) atriyal flatterların triküspit kapak anülüsü etrafındaki ileti hızlarının farkı hala tam olarak aydınlatılmamıştır. Bu çalışma, triküspit kapak anülüsü etrafındaki ileti hızı (CV) ve iletim alanının (CA) (msn) elektroanatomik haritalama ile değerlendirmeyi amaçlamıştır.

Yöntemler: İstmus bağımlı atriyal flatteri olan (CCW 25; CW 5) ardışık 30 hastada (ortalama yaş 61±16), taşikardi sırasında elektoanatomik haritalama uygulandı. CV ve CA ölçümlerini, üst septum (US), alt septum (LS), istmus (I), üst lateral duvar (UL) ve alt lateral duvar (LL) olmak üzere sağ atriyumun beş bölgesinde isokronal haritada yeni ölçüm metotları ile yaptık.

Bulgular: Toplamda LS'nin CV'si diğer bölgelere kıyasla belirgin derecede yavaş idi (m/sec: US, 0.57±0.18; LS, 0.43±0.18; UL, 0.60±0.26; LL, 0.53±0.20; I, 0.50±0.17; p<0.05) ve US ve UL'nin CA'sı diğer bölgelerden belirgin derecede geniş idi (mm^2/sec: US, 34.5±16.2; LS, 16.2±9.5; UL, 40.0±14.1; LL, 27.0±17.0;I, 16.8±8.5; p<0.0001). CCW ve CW atriyal flatterlerinde, eşit bölünmüş beş alan arasında, CV ve CA açısından belirgin fark izlenmedi.

Sonuç: Her iki atriyal flatter tipinde de, LS'nin CV'si diğer bölgelerden belirgin olarak kısa ve alt atriyumun CA'sı üst atriyumdan belirgin şekilde küçük olarak bulundu. *(Anadolu Kardiyol Derg 2011; 11: 711-6)*

Anahtar kelimeler: Atriyal flatter, iletim hızı, ileti bölgesi, elektroanatomik haritalama sistemi

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Introduction

Atrial flutter (AFL) is the most common macro-reentrant atrial tachyarrhythmia. The reentrant circuit of the AFL is bordered anteriorly by the tricuspid annulus and posteriorly by the vena cavae orifices, the crista terminalis and the Eustachian ridge (1).

The anatomical isthmus between the inferior vena cava and the low tricuspid ring is known as the cavotricuspid isthmus (CTI). Previous studies showed that the CTI is an area of slow conduction and is related to the induction and maintenance of common AFL (2, 3). The CTI has been considered as a main target for catheter ablation because of its high efficacy (4, 5).

Slowing of the conduction velocity (CV) is one of the most important necessities for initiation of reentrant tachyarrhythmias (6). This slow conduction may result from anisotropic characteristics or persistence of diseased atrial tissue. Because of the existence of multiple verges and orifices, the low right atrium is a structure for potential anisotropism (7).

However, there is still some controversy about the CV and the exact location of the slow conduction area in the reentrant circuit (8). The difference of the CV around the tricuspid valve annulus (TVA) between the counter-clockwise (CCW) and the clockwise (CW) AFL has not been well clarified, either.

The electroanatomical (CARTO; Biosense Webster Ltd., Israel) mapping system is a reliable method to show a three-dimensional, high resolution anatomic activation map of the entire AFL circuit (9) and also with this system, the distance and the time difference can be measured and thus the CV and conducting area (CA) can be calculated. The CA measured by CARTO mapping system is a value, which is affected by both the CV and the size of the area. Therefore, it may have a potential to differentiate the characteristics between the CCW and the CW AFL.

In this study, we evaluated the CV and the CA around the TVA using the CARTO mapping system and investigated the difference of these values between the two groups of isthmus-dependent AFLs.

Methods

Patients

Thirty patients (27 men, 3 women; mean age; 61±16 years) who were referred for radiofrequency (RF) catheter ablation of symptomatic isthmus-dependent AFL (CCW: 25; CW: 5) were recruited into the study.

CCW AFL was considered to be present, if the surface electrocardiography (ECG) showed flutter waves of the typical sawtooth configuration with negative polarity in leads II, III, AVF and isoelectric or positive in lead V1.

The CW AFL was considered to be present, if flutter waves were positive or biphasic in leads II, III and AVF with a varying morphology in lead V1.

Informed consent was obtained from all patients before the electrophysiological study and catheter ablation.

Electrophysiological study

All antiarrhythmic drugs were discontinued for at least five half-lives before the procedure except amiodarone, which was interrupted for eight half-lives before the procedure. The procedure was performed after 4 to 6 hours of fasting. Under fluoroscopic guidance, a steerable quadripolar catheter with 5-mm electrode spacing was placed in the right ventricular apex. Quadripolar catheter with 2-mm electrode spacing was placed in the His bundle region. A 7-F, 20-pole deflectable Halo catheter with 10-mm paired spacing (Cordis-Webster, Inc., Baldwin Park, California) was positioned in the coronary sinus (CS) and the proximal poles were positioned around the tricuspid annulus. All intracardiac electrograms were displayed at 5 to 20 mV/cm after filtering from 30 to 500 Hz.

Electroanatomical three-dimensional mapping

Three-dimensional electroanatomical mapping was performed using the CARTO system. This system include a location pad, the CARTO processor, a monitor and a workstation (Silicon Graphics International Corp., Fremont, California) as well as a sensor-equipped 4-mm-tip deflectable mapping catheter (Navistar, Biosense Webster, Diamond Bar, California). The potential of CS from the Halo catheter was used as a fixed time reference to determine activation sequence. The CARTO mapping was performed during the AFL and a replica of the right atrium (RA) was created. Both the intracardiac electrograms of the Halo catheter and the activation map of the CARTO showed a craniocaudal activation sequence in the septal region during the CCW AFL. An opposite activation sequence was observed during the CW AFL. We took care not to place the catheter in the coronary sinus during the mapping of the septal region. Pacing at a cycle length 20-40 msec shorter than the AFL cycle length was also performed from the TV-IVC isthmus in all cases to confirm the isthmus dependence of the AFL by demonstrating same post pacing interval as tachycardia cycle length.

Measurement methods of conduction velocity and conducting area

Isochronal map was reconstructed with following parameters. Isochronal step: 10-20 msec, Fill threshold: 10-20, Head meets tail threshold: 80-90%. We evaluated the CV (m/sec) and the CA (mm^2/sec) in equally divided five areas of the RA; i.e. upper septum (US), lower septum (LS), cavotricuspid isthmus (I), upper lateral wall (UL) and lower lateral wall (LL) in the isochronal map. We divided these five segments equally using the plane where we could observe the TVA from an anterior view (Fig. 1, white dashed line). TVA was determined by the points where the A/V ratio of mapping catheter was close to 1. Measurement of the length was performed just on the TVA. The CV was calculated by the equation shown as below.

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CV = Length / Conduction time

According to these methods, each divided segment has usually 2 to 6 isochronal steps (30 to 60 msec). If it was difficult to decide which segment an isochronal step belonged to, we excluded the isochronal step from analysis. The CA of the five segments of the RA was calculated using multiple planes of isochronal map (Fig. 2). These planes were selected where the divided area maximizes its area. The CA was calculated as the ratio of area divided by the difference in conduction time between borders.

CA = Area / Conduction time

The part of head meets tail, the posterior RA near the double potential and superior vena cava (SVC), were excluded from the analysis. The ostium of SVC was defined as the point of inflection between the SVC wall and the RA wall. The Osiris 4.07 software (www.sim.hcuge.ch/uin/) was used for these measurements.

Radiofrequency Catheter Ablation

After the mapping study, radiofrequency (RF) catheter ablation was performed for all patients. For RF catheter ablation, a linear lesion was created on the CTI by 8-mm-tip deflectable ablation catheter (Blazer XP Large Curve, EP Technologies) during AFL or pacing from the proximal coronary during sinus rhythm. The RF catheter temperature was 55°C-60°C and the duration of application was 30-60 seconds for each ablation point. The end point of ablation was bidirectional conduction block across the CTI, as revealed by the change in the sequence of atrial potentials of the Halo catheter during pacing from both sides of the isthmus.

Statistical analysis

All statistics were performed using the Statview 5.0 software (SAS Institute, Cary, North Carolina, USA). Continuous variables are presented as the mean±SD values. The statistical significance of the difference in the CV and the CA between the two groups was assessed using the Student's t-test and Chi-square test and the comparison of the values in the five divided areas was performed by one-way analysis of variance (ANOVA) method. A p value less than 0.05 was considered as statistically significant.

Results

Study population

No significant differences were revealed between the two groups based on demographic and clinical characteristics. Echocardiographic study was performed before the procedure and the initial echocardiographic examinations revealed no significant difference in atrial dimensions, RA pressures and ventricular systolic function between the two groups. The demographic and clinical characteristics of the patients are summarized in Table 1.

Table 1. Patient characteristics

Variables	CCW AFL (n=25)	CW (n=5)	p*
Age, years	62.2±11.8	55.4±30.2	0.386
Male, n	22	5	0.414
LVEF, %	62.0±10.5	57.8±9.8	0.459
LAD, mm	41.5±9.1	46.5±6.4	0.281
RVP, mmHg	27.0±7.5	28.0±4.4	0.829
Structural heart disease, n (%)	7 (28)	2 (40)	0.593
Hypertension, n (%)	10 (40)	2 (40)	>0.99
Antiarrhythmic drugs, n (%)	5 (20)	1 (20)	>0.99
AFL cycle length, msec	254±32	249±26	0.706
Diameter of TVA, mm	43.4±7.2	43.8±3.7	0.859

Values are presented as mean±SD and number/ percentage
*Chi-square test and unpaired Student's t-test
AFL - atrial flutter, LAD - left atrial diameter, LVEF - left ventricular ejection fraction, RVP - right ventricular pressure, TVA - tricuspid valve area

Three-dimensional electroanatomical activation mapping

Twenty five patients had only CCW AFL, 5 patients had only CW AFL and no patient had both. The mean atrial cycle length was 254±32 msec and 249±26 msec during CCW and CW AFL respectively. Complete CARTO mapping was constructed for all 30 patients. An average of 200±51 mapping points was sampled for constructing the activation map during AFL.

Conduction velocity and conducting area

In total, the CV of the LS was significantly slower than other areas (m/sec: US, 0.57±0.18; LS, 0.43±0.18; UL, 0.60±0.26; LL, 0.53±0.20; I, 0.50±0.17; p < 0.05), and the CA of the US and UL were significantly larger than other areas (mm^2/sec: US, 34.5±16.2; LS, 16.2±9.5; UL, 40.0±14.1; LL, 27.0±17.0; I, 16.8±8.5; p<0.0001) (Fig. 3).

There was no significant difference in the CV between the CCW and the CW AFL (m/sec: CCW; US, 0.57±0.20; LS, 0.44±0.18; UL, 0.56±0.21; LL, 0.51±0.16; I, 0.62±0.28: CW; US, 0.59±0.10; LS, 0.41±0.19; UL, 0.43±0.15; LL, 0.44±0.10; I, 0.51±0.17; p=NS) (Fig. 4).

There was also no significant difference in the CA of five divided areas between the CCW and the CW AFL(mm^2/sec: CCW; US, 34.1±15.8; LS, 16.4±10.2; UL, 40.5±14.4; LL, 28.4±17.8; I, 18.1±8.4: CW; US, 36.5±20.0; LS, 15.7±5.2; UL, 37.7±14.3; LL, 20.7±11.9; I, 11.0±7.1; p = NS) (Fig. 5).

In both groups, the CV of the LS was significantly slower than other areas and the CA of the lower atrium was significantly smaller than the upper atrium.

Discussion

The major findings of the present study were the following. First, the CV of the lower septum was slower than other areas in both of the CCW and the CW AFL groups using the novel measurement method in the isochronal map of the electroanatomical mapping. And the CA of the upper septum and the upper

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lateral wall were larger than other areas in both groups. Second, there was no difference between the two AFLs in terms of the CV and the CA of equally divided five areas and there was no difference in the average values of the CV and the CA between the two AFLs.

Conduction velocity of the isthmus

The CV of the isthmus has been shown to be slower than that of either the RA free wall (9-11) or interatrial septum (7, 12-14) but the presented data estimating the CV were inconsistent among the studies ranging widely from 0.33 to 0.74 m/sec. We assume that this variation depends on the variation of the CV data derived from selected two points. During AFL, the activation wave front usually travels parallel to the TVA. However, it is hard to measure the CV precisely unless the two target points were set parallel to the TVA when CARTO mapping system is used directly. Therefore, we did not directly take the value of the CV from the CARTO system and measured the CV only on the TVA using the isochronal map. By this method, all points of the activation on the TVA should be averaged spatially and it is possible to reveal the characteristics of the CV correctly in each part of the five divided areas in the RA. Waki et al. (15) showed that the muscular arrangement in the zone immediately inferior to the coronary sinus ostium had abundant cross-over and interlacing trabeculae in 37 (74%) out of 50 heart specimens. They also showed that trabeculae to the right- and left-hand sides of the ostium are interconnected along the inferior rim of this area and speculated that nonuniform anisotropic conduction could occur in this area of right atrium. This anatomical background may lead to a conduction delay of lower septum and CTI.

Conduction velocity and conducting area in the right atrium

Tai et al. (12) and Feld et al. (11) found the CV around the TVA to be slowest in the CTI, compared to the septal or free wall segments of the TVA (0.336±0.045; 0.642±0.046 m/sec; respectively). In these studies entrainment pacing and multi-electrode catheter mapping techniques were used for the calculation of the CV. Shilling et al. (10) measured the CV using non-contact mapping system (Ensite) and showed that the CV of the isthmus was slower than other areas although it was relatively high (0.74±0.36 m/sec). In a relatively recent study, Chen et al. (16) also used the non-contact mapping system and showed two slow conduction zones in the septal CTI and lateral free wall (0.82±0.72; 0.99±0.85 m/sec; respectively) compared to the other areas (1.58±1.05 ~ 1.68±1.00 m/sec). In both studies using Ensite system, the CV was clearly higher than that of other studies using the electrode catheters or CARTO system. We suspect that the reason of the result is that the average CV of the area near the TVA and posterior wall may have been presented in the Ensite system, although there should be differences of the length of reentry circuit between the area close to the TV and the posterior right atrium. In their study using the direct measurement of CV from the CARTO system, Hassankhani et al. (9) has shown that the
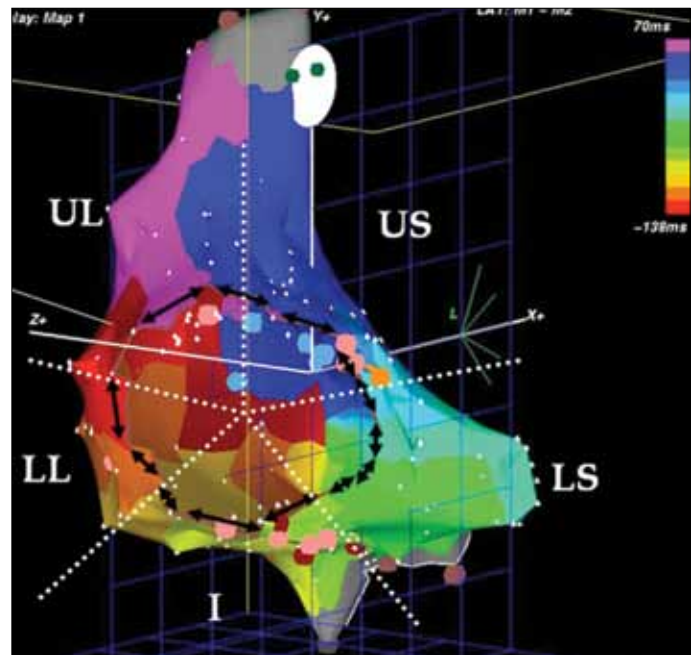

Figure 1. Measurement of the conduction velocity (CV) in isochronal map
The black arrow showed the length of every 15 msec on the tricuspid valve annulus. The CV (m/sec) was measured as the ratio of length divided by the conduction time between borders. The CVs within each segment of equally divided five areas were averaged. Note, LL and UL have 2 isochronal steps (15msec x 2), while LS has 4 isochronal steps (15 msec x 4) indicating that there is slow conduction in LS segment
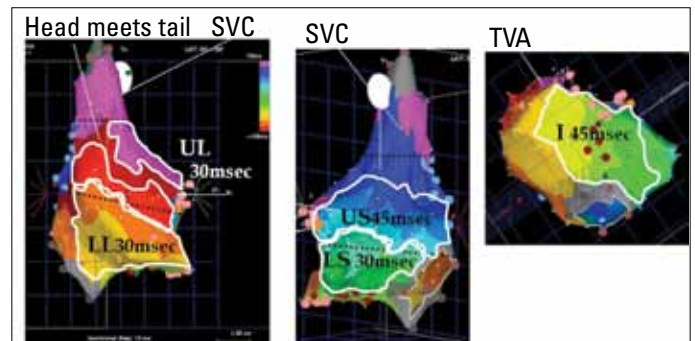I - isthmus, LL - left lateral, LS - lower septum, US - upper septum

Figure 2. Measurement of the conducting area (CA) in isochronal map
The CA of the five segments of the right atrium was calculated using multiple planes of isochronal map with 15 msec step. These planes were selected where the divided area maximizes its area. The CA (mm²/msec) was calculated as the ratio of area(surrounded by the white border) divided by the conduction time between borders. The part of head meets tail, the posterior right atrium near the double potential and superior vena cava (SVC) were excluded from the analysis
I - isthmus, LL - left lateral, LS - lower septum, US - upper septum TVA - tricuspid valve annulus

medial isthmus and inferior septum were the most slowly conducting areas in the isthmus-dependent right AFL (0.56±0.16; 0.59±0.24 m/sec; respectively). Sawa et al. (13) also measured the CV by the CARTO system and reported that the medial and the septal isthmus were the slowest CV areas of the RA (0.44±0.17; 0.45±0.22 m/sec; respectively). In our study, we also used the CARTO system and found the similar results that the CV in the lower septum was slower than in other areas in both groups among the relatively higher numbers of patients than that
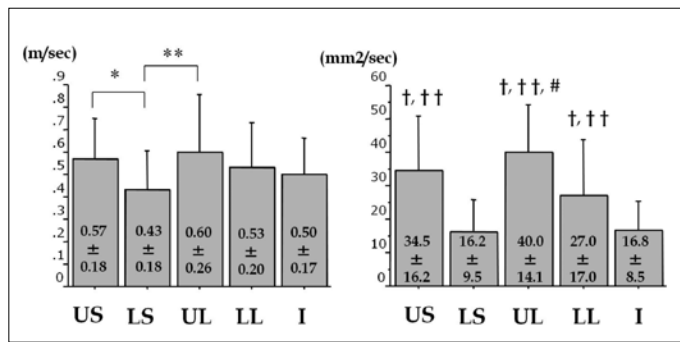
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Figure 3. CV (left) and CA (right) among five segments of the RA

The CV of the LS was significantly slower than other areas and the CA of the US and UL were significantly larger than other areas

All data are presented as mean±SD

*p<0.05 **p<0.01 †p<0.01 vs LS ††p<0.01 vs I #p<0.01 vs LL by ANOVA

CA - conduction area, CV - conduction velocity, I-isthmus, LL - left lateral, LS - lower septum, US - upper septum
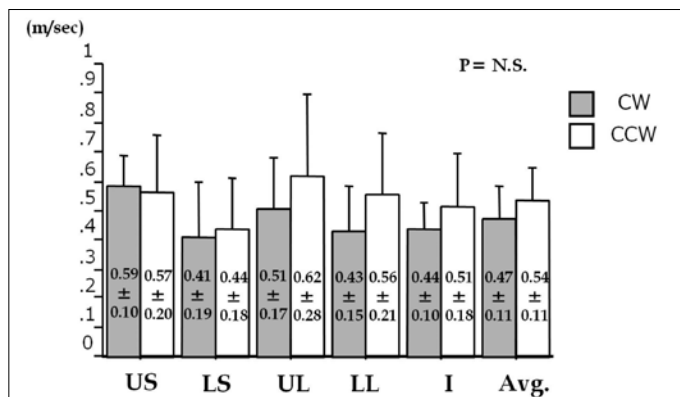

Figure 4. Comparison of the conduction velocity between CW and CCW groups

There was no significant difference in the CV of five divided areas between the CCW and the CW AFLs. In both groups the CV of the LS was significantly slower than other areas.

All data are presented as mean±SD.

AFL - atrial flutter, Avg - average, CV - conduction velocity, CCW - counter clockwise, CW - clockwise, I-isthmus, LL - left lateral, LS - lower septum, US - upper septum
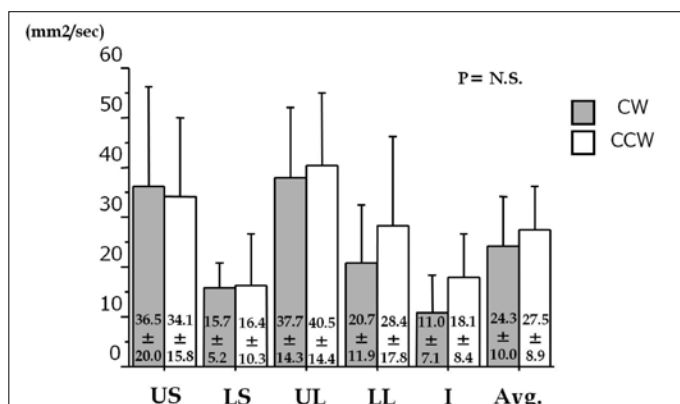

Figure 5. Comparison of the conducting area (CA) between CW and CCW groups

There was no significant difference in the CA of five divided areas between the CCW and the CW AFLs and the CA of the lower atrium was significantly smaller than the upper atrium.

All data are presented as mean±SD.

AFL - atrial flutter, Avg - average, CA - conduction area, CCW - counter clockwise, CW - clockwise, I-isthmus, LL - left lateral, LS - lower septum, US - upper septum

of the previous studies. However, the unique aspect in this study was its measurement technique of CV. We did not obtain the CV directly from the CARTO system because the CARTO system software assumes a linear geometry and measures the CV between two points along a straight line even when the conduction travels in a different direction. Although the common atrial flutter is generally a stable arrhythmia with a stable cycle length, the CV in the area close to the tricuspid valve (TV) and in the posterior RA may be quite different from each other because of the shortness of reentry circuit at the area close to the TV compared to the posterior right atrium. Therefore, we measured the CV on the TV using the isochronal map and also evaluated the CA. The CA in the lower RA was significantly smaller than the upper RA. We think that this result supported the result of the CV and emphasized that slow conduction area was almost same in both AFL groups.

Comparison of CW and CCW AFL

Tai et al. (12) and Feld et al. (11) demonstrated rate-dependent slowing of the trans-isthmus conduction, whereas Kinder et al. (17) and Lin et al. (7) did not show such a phenomenon using a similar pacing protocol. We think that these differences may depend on using different kinds of catheters (they may cause different positioning of the electrodes) and different calculating methods. CCW and CW CVs of CTI seem to be also different in AFL patients compared with the control (11, 17, 18). Morita et al. (19) has found that the CW conduction in the low RA isthmus was significantly slower than the CCW direction. In our study, there was no difference of the CV and the CA of the RA between the CCW and the CW AFL groups. This may be explained by the different responses to the pacing and to the tachycardia of constant rate. Shah et al. (14) used non-contact mapping system for comparing the CV between CCW and CW AFLs. Similar to our study, they showed no difference between the two groups.

Study limitations

The major limitation of this study was the measurement of the CA, which was performed on two-dimensional map. The CV and the CA were obtained from most of the parts of the RA but no data was obtained from some parts of the atrium especially the posterior part of the RA. Therefore, it was difficult to evaluate the CV and the CA of these sites. Despite the advances of the electroanatomical mapping system, some points in isochronal map are still virtual. The antiarrhythmic drug therapy may have some chronic effects on the right atrium even after the discontinuation of all antiarrhythmic drugs. However, in our study, there was no difference between the two AFL groups regarding the number of the antiarrhythmic agents used.

Conclusions

In both of the CCW and CW AFLs, the CV of the lower septum was significantly slower than other areas, which was measured

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by a novel method using the electroanatomical map. The CA of the lower atrium was also significantly smaller than the upper atrium. There were no significant differences between the CCW and the CW AFLs, in terms of the CV and the CA of the equally divided five areas.

Conflict of interest: None declared.

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