The muscle bundle approach for catheter ablation of the cavotricuspid isthmus: a propensity score-matched cohort study

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Abstract

Introduction

Pathological studies have demonstrated that the cavotricuspid isthmus (CTI) is often composed of discrete muscle bundles that correlate with high-voltage local electrograms.

The main objective was to demonstrate that ablation of high-voltage muscle bundles in the cavotricuspid isthmus (CTI), identified using an intracardiac mapping system, reduces radiofrequency (RF) time compared to the conventional technique.

Methods

A retrospective analysis of patients who had undergone CTI ablation guided by a mapping system. The patients were divided into two groups according to operator experience and selected by propensity score-matched analysis: group A, RF delivery in high-voltage bundles and group B, RF delivery producing a contiguous line of ablation lesions along the entire CTI length.

Results

Thirty-eight patients [92.1% male, 64 yrs (57-70)] were selected, 19 in each group. There were no differences in baseline characteristics or clinical results: success (A: 94.7% vs B: 94.7%), complications (A: 5.3% vs B: 0%) and recurrence (A: 10.5% vs B: 5.3%). In the procedures in group A, fewer RF applications were delivered [14 (9–19) vs 20 (2–25); $P < 0.05$] with greater contact force [14.5 g (13–16.2) vs 12 g (9-14); $P < 0.01$] and greater lesion size index (LSI) [5.3 (4.9–6) vs 4.5 (4.1–4.7); $P < 0.001$]. The RF time was less ($P < 0.001$) in group A [310 s (211–479) vs 577 s (312–858)].

Conclusions

Application of RF in CTI muscle bundles reduces RF time, compared to conventional linear ablation, with similar clinical results.

Keywords: Catheter ablation; Atrial flutter; Cavotricuspid isthmus; Contact force; Mapping system

Introduction

Catheter ablation of common atrial flutter is a procedure that yields excellent results. Since it was first described, the technique has been based on delivering radiofrequency (RF) along the entire length of the cavotricuspid isthmus (CTI), from the tricuspid annulus to the inferior vena cava.

Pathological studies have demonstrated that the arrangement of the muscle bundles arising from the crista terminalis is irregular, with connective tissue interspersed between them.[1,2] The thickness of the bundles within the CTI is variable and correlate with the amplitude of the atrial electrogram.[3]

Various studies have been published in which the RF time was significantly reduced by delivering energy exclusively at the points of maximum voltage of atrial electrograms.[4,5]

The discrete muscle bundles can be identified by electro-anatomical mapping systems. Adjusting the voltage scale the system can differentially identify areas with an arrangement similar to a muscle bundle of higher voltage than the adjacent areas. Delivering energy in those bundles has also been shown to reduce the RF time compared to conventional linear ablation.[6]

The main objective of our study is to demonstrate that CTI ablation guided by the identification of high-voltage muscle bundles, using ablation catheters with contact force sensors, reduces the RF time compared to conventional ablation.

Methods

Patient selection

All patients indicated for common atrial flutter ablation in whom the Ensite™-NavX™ Precision™ cardiac mapping system was used were consecutively included during the same study period.

Although inclusion was not randomized, the distribution of patients was determined by the normal scheduling of activity in our unit. Those operators for the procedure decided which technique to use in each patient according to their experience in voltage-mapping-guided ablation. Patients who underwent an ablation procedure guided by voltage mapping were included in group A; those who received a conventional linear ablation procedure were assigned to group B. Patients with congenital heart disease, those in whom ablation of another substrate was performed in the same procedure and those who had undergone previous CTI ablation were not included. After discharge, patients were scheduled for a 6-month follow-up clinical visit.

All the patients signed the informed consent. The study was approved by the ethics committee.

Electrophysiological study and catheter ablation

In our unit, the zero-fluoroscopy approach is the first-choice technique for all atrial flutter ablation procedures.[7] All the procedures used the Ensite™-NavX™ Precision™ cardiac mapping system (Abbott, Inc., IL, USA). The duodecapolar catheter (Livewire™, Abbott, Inc., IL, USA) was used in all cases and was positioned in the tricuspid annulus and the coronary sinus, guided exclusively by the navigation system. The 3D-anatomical reconstruction of the right atrium and the voltage and activation maps were performed by the ablation catheter (TactiCath™ Quartz, Abbott, Inc., IL, USA).

Acquisition of voltage maps

In all the cases in group A, and optionally in group B, a 3D reconstruction of the right atrium was created during pacing from the coronary sinus or during atrial flutter, using the ablation catheter. We considered the tricuspid annulus area to be that in which points were recorded with the atrial electrogram that were of lower amplitude than the ventricular electrogram. The end of the CTI was drawn at the points where an atrial electrogram was recorded on the distal electrode but not on the proximal electrode. An area, subdivided into 6 sectors, was arbitrarily defined with the following limits: the tricuspid annulus (anterior), the inferior vena cava (posterior), the ostium of the coronary sinus (septal) and the free wall of the right atrium (lateral) (Figure 1). The voltage map was acquired with the ablation catheter in flutter or during pacing at 500–600 ms from the coronary sinus; a minimum of 30 homogeneously distributed points per map were automatically acquired, only when the contact force was at least 5 g.

The intracardiac electrograms were filtered from 30 to 500 Hz and measured at a sweep speed of 100 mm/s. We used a peak-to-peak voltage scale of 0.1–1.5 mV.[10] We identified an area of voltage higher than the neighbouring (anterior and posterior) areas, such that the voltage scale was uniform in most of that area, as a high-voltage bundle. If muscle bundles were not identified (mainly because most points in the CTI had a voltage higher than 1.5 mV), we modified the voltage scale in a stepwise manner, gradually raising the upper voltage limit until we managed to identify one or more muscle bundles (Figure 2), although in some cases the maximum value needed to be reduced.

Catheter ablation

In both groups the programmed power was limited to 40 W, with an irrigation flow rate of 17 mL/min. It was recommended that the initial contact force should be at least 10 g, with a target lesion size index (LSI) of 5–6. The RF applications were delivered during flutter or during septal pacing, depending on the patient's baseline rhythm. If necessary, at the operator's discretion, a sheath (Agilis™, Abbott, Inc., IL, USA) was used.

Group A: individual applications were performed in the bundle containing the point of highest voltage, regardless of its location. The extent of the applications within the bundle was not predetermined; it could be performed along its entire length or in adjacent areas before moving on to the next bundle, if any, or extending the applications to the whole CTI. Radiofrequency was not delivered at points where the electrogram amplitude had been reduced by a previous application.

Group B: the conventional technique was to perform a linear ablation between the tricuspid annulus and the inferior vena cava. If block was not achieved, gap areas were sought and individual applications and/or a new linear ablation were performed, if necessary.

The objective in both groups was bidirectional block (BDB), which was confirmed by differential pacing or finding double potentials along the ablation line. If necessary, an activation map was generated to demonstrate the BDB. The procedure was considered completed after 30 minutes' waiting time.

Analysis of the procedure times

The total procedure time was measured from the start of the punctures to the removal of the catheters, including the waiting time. The diagnostic electrophysiological (EP) study time was from the start of the punctures to the first RF delivery, and the ablation time was from the first RF delivery to the end of the last, whether or not BDB was achieved. The RF time was the sum of the times of all the RF deliveries, irrespective of their duration and the parameters achieved. The number of RF deliveries was calculated without regard to their duration and the RF parameters obtained.

Statistical analysis

The continuous variables are expressed as median (1st and 3rd quartiles) and the qualitative variables as absolute values and percentages. The Mann-Whitney U test was used to compare the quantitative variables and the chi-square test or Fisher's exact test for the qualitative variables. A value of $P < 0.05$ was considered statistically significant.

We used the R program version 4.02 for Macintosh for statistical analysis, with the MatchIt module for propensity score analysis. The propensity score-matched analysis was performed by pairing the individuals in the control group and the intervention group according to a propensity index. The propensity index was calculated with the match-it function, using the variables related to the "belonging to control or intervention group" variable with a *P*-value of less than 0.2, as well as the variables related to RF time.

Results

Sixty-six patients were included, 38 in group A and 28 in group B. Following the propensity score analysis, 38 patients were selected (19 in each group). The baseline characteristics are presented and compared in Table 1. No significant differences were observed between the two groups.

Atrial flutter was the baseline rhythm in similar proportions in each group (52.6% vs 36.8%; $P = 0.32$). The 3D reconstruction of the right atrium was carried out for all the procedures in group A (100%) and for 47.4% in group B ($P < 0.001$). Fluoroscopy was required in 26.7% of the procedures in group B and was not used in group A ($P < 0.05$).

In group A, 2038 points were acquired (median 106, (72-136). The median maximum voltage was 6.4 mV (3.6–7; minimum 2.11, maximum 15.2) and the median minimum voltage was 0.21 mV

(0.17–72-1360.41; minimum 0.12, maximum 0.9). The maximum voltage value had to be increased to identify a bundle in 72.2% of cases; the maximum value of the voltage scale was 3.3 mV (1.7–4.1). We identified a total of 23 bundles, a single bundle in 15 patients and two bundles in 4. The most common location was the middle third (16 cases); bundles were found in the posterior third in 4 cases and in the anterior third in 2. In 3 patients, the limits of the bundle extended over two sectors (anterior and middle in 1 patient and middle and posterior in 2). The point of maximum voltage was located in the bundle in the middle third in 14 cases, in the posterior third in 3 and in the anterior third in 2.

The procedure was successfully accomplished in 18 cases in each group (A: 94.7% vs B: 94.7%; $P = 1$); a patient in group A suffered a severe hematoma in the puncture area and in group B there were no complications (5.3% vs 0%; $P = 1$). The recurrence rate was 10.5% (2 cases) in group A and 5.3% (1 case) in group B ($P = 1$). A catheter sheath was used to improve the stability of the ablation catheter in a similar number of procedures (10.5% vs 15.8%; $P = 0.1$). There was no significant different in the total procedure time (median 107.5 min vs 114 min; $P = 0.69$); the diagnostic EP study time was less in group B (median 59 min vs 50 min; $P < 0.01$) and the ablation time was less in group A (median 22.6 min vs 45.2 min; $P= 0.064$).

Fewer RF lesions were performed in the procedures in group A (14 vs 20; $P = 0.08$) with better RF parameters: greater contact force (median 14.5 g vs 12 g; $P < 0.01$) and higher LSI value (median 5.3 vs 4.5; $P < 0.001$).

The radiofrequency time (Figure 3) was less in group A (median 310 s vs 577 s; $P = 0.01$). In no case in group B was the procedure successfully accomplished with less than 120 s of radiofrequency, whereas this did occur in 10.5% (2 cases) of the procedures in group A ($P < 0.05$).

Discussion

The main finding of our study is that the high-voltage muscle bundle approach, with the bundles identified using an electroanatomical navigation system, reduces the radiofrequency time compared to conventional CTI ablation. There is no difference in the ablation procedure time and the clinical results (success, complications and recurrence).

Our results support the hypothesis that atrial flutter conduction could occur preferentially over one or more muscle bundles and that it is therefore unnecessary to perform an ablation over the whole length of the CTI.[8]

In anatomical studies it has been observed that neither the distribution of the muscle bundles in the CTI, nor that of the connective tissue separating them, is uniform in most cases.[1,2] Furthermore, the thickness of these muscle bundles is also variable in the anatomical areas into which the CTI has been divided.[1,2] The thickness (measured by intracardiac echocardiography) could be estimated from the amplitude of the atrial electrogram.[3]

In the first description of the maximum voltage-guided ablation technique, the operators delivered RF energy at the points of highest voltage in the atrial electrogram in a sequential manner. After a non-success RF delivery the CTI was re-mapped and other highest voltage atrial electrogram was localized where RF was again delivered. They did not use an electro-anatomic mapping to identify the muscle bundles and fluoroscopy was the only guide in the procedure. Therefore, the radiofrequency applications could have been delivered in adjacent areas of the previous RF lesion or in different muscle bundles. Even so, this technique has been shown to reduce the radiofrequency time compared to conventional linear ablation[4,5] Others authors delivering RF in low-voltage sites identified by electro-anatomic mapping systems have obtained dispare results compared with the anatomical conventional approach.[9]

The navigation system makes it possible to generate a voltage map of the CTI which is projected onto the anatomy of the right atrium. Adjacent points of high voltage separated on both sides by points of lower voltage could be defined as a differentiated area within the CTI similar to a muscle bundle.[9] In all cases we were able to identify at least one muscle bundle. To do so, however, we had to increase the maximum voltage, since most of the CTI had a voltage greater than 1.5 mV, probably due to a compact arrangement of the muscle bundles without connective tissue between them. The ablation catheter may not be the most suitable instrument to achieve optimum discrimination of atrial voltages, because of the interelectrode distance; multipolar catheters could solve this issue by ultra-high-density mapping.[10] We used an irrigated-tip catheter with contact force information to generate the voltage map, only acquiring points at which a value of more than 5 g was obtained, although there is no general agreement on this figure.[11] Measurement of local impedance and reactance could estimate tissue viability, distinguishing between connective tissue and muscle tissue. This technology, however, does not yet include contact force measurement, and reduced electrical coupling index values (indicative of non-viable tissue) could correspond to areas of muscle in which proper contact is not achieved.[12]

The RF time in our study group was similar to those reported by studies in which voltage-guided ablation was performed.[4,5] In these studies, RF was delivered during septal pacing and even patients who arrived in flutter were converted to sinus rhythm; previous analyses showed that RF delivery during septal pacing was significantly shorter.In our overall series (n = 38) of voltage-guided procedures, the RF time was longer when the baseline rhythm was flutter (n=18) than when the energy was delivered during septal pacing (n=30) [median 479 s (225-652) vs 260 s (186-378); P=0.034]. The anatomical variations that occur in the CTI during atrial and ventricular contraction, which are more common during atrial flutter, may adversely affect the stability of the ablation catheter tip, prolonging the RF time.

The studies that have analysed the influence of contact force on RF time have obtained disparate results. When the conventional linear ablation technique was the one used in the study group (operator aware of the contact force parameters) and the control group (operator unaware of those parameters), the RF time was no different in most studies.[12,13] Significant differences were described in a study of similar design, though with high RF time values (10 min vs 15.9 min; $P < 0.05$).[14] In the control group in our study we observed an RF time similar to, and even shorter than, that reported by the previous studies.

In addition, disparate results were also observed in the studies that analysed operator awareness of the contact force in a maximum-voltage-guided ablation approach. In one of them[15] the RF time (5.1 min) was similar to that obtained in group A in our study (310 s); in another, however, the time was clearly longer (623 s).[16]

The LSI values obtained in both groups in our study are lower than the recommended range for CTI ablation. However, studies in which values higher than 6 were reached did not achieve RF times shorter than those obtained in our study.[13,15]

Even though the value of the degree of contact force was lower in the control group (12 g vs 14.5 g), it did not differ significantly from the results reported by other authors.[14,17] The degree of contact of the ablation catheter in the anterior third is less than that obtained in the middle and posterior thirds.[14,17] The anterior third approach is obligatory in the conventional linear technique, but not necessary in the muscle bundle approach; in the study group, the middle third was the most frequent site of approach. This also has the advantage of involving fewer applications in the anterior third, which is closer to the right coronary artery.

Is there a muscle bundle in the CTI with preferential conduction that is the only one that needs to be ablated to achieve bidirectional block?

This hypothesis is supported by the fact that the CTI can be blocked with a single (defined as radiofrequency time duration less than 120 ms) application, a phenomenon that has been reported in as many as 8% of cases.[18] In our overall series of 38 patients in group A, BDB was achieved in 21% of cases with less than 120 seconds of RF; moreover, in 82% of cases it was attained by ablating the bundle where the point of highest voltage was obtained. On the other hand, several authors have demonstrated the presence of bystander areas that played no part in maintaining atrial flutter. It was not necessary to apply radiofrequency in those areas to achieve bidirectional block.[19,20]

Limitations

The main limitation of our study is its retrospective and non-randomized nature. However, performing a propensity score analysis made the groups very homogeneous. The sample size is small and the study was not designed to assess the rate of recurrence and complications. However, the published randomized studies of RF time difference did not require a much larger sample size.

We did not analyse the presence of sub-Eustachian recesses, which have been shown to influence RF time. Nor did we use other imaging techniques to confirm the anatomy of the CTI, so as not to increase the complexity of the procedure. Our results are similar to those of other studies that do not address the presence of these recesses.

Conclusions

Ablation guided by identification of muscle bundles is a promising procedure, in reducing radiofrequency time; however, it needs to be validated by prospective studies with a larger number of patients.

Our data support the theory that in the majority of patients there is a muscle bundle of the CTI with preferential conduction needed to maintain common flutter.

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Figure legends

Figure 1: Tridimensional reconstruction of the right atrium. Cranial oblique left anterior view of the cavotricuspid isthmus. Area subdivided in six sectors with the next limits: the tricuspid annulus (TA), the inferior vena cava (IVC), the ostium of the coronary sinus (CS) and the free wall of the right atrium (RAFW). The duodecapolar catheter (blue) was placed into the coronary sinus.

Figure 2: Panel A: Voltage map of the cavotricuspid isthmus. The basal scale value limits were 0.1-1.5 mV. The white arrow marks the maximum voltage point (6.80 mV) located into the middle sector.
Panel B: Voltage map after raising the upper limit of the scale value to 3.71 mV. A unique muscle bundle with an oblique course is identified. The maximum voltage point is within the bundle.
DC-CS: decapolar catheter in coronart sinus; IVC: inferior vena cava; RAFW: free wall of the right atrium; TA: tricuspid annulus

Figure 3: Dot plot of individual radiofrequency time and the median value (1st and 3rd quartiles) in both groups.

Figure 4: Cumulative success in achieving bidirectional cavotricuspid isthmus block as a function of duration of radiofrequency (RF) time. Ablation of the muscle bundle (group A) resulted in complete CTI block in a larger proportion of patients sooner than the conventional approach (group B). Within the first 600 seconds the success was achieve in 89.4% of patients in group A vs only in 47.4% of patients in group B ($p<0.001$).

Figure 1

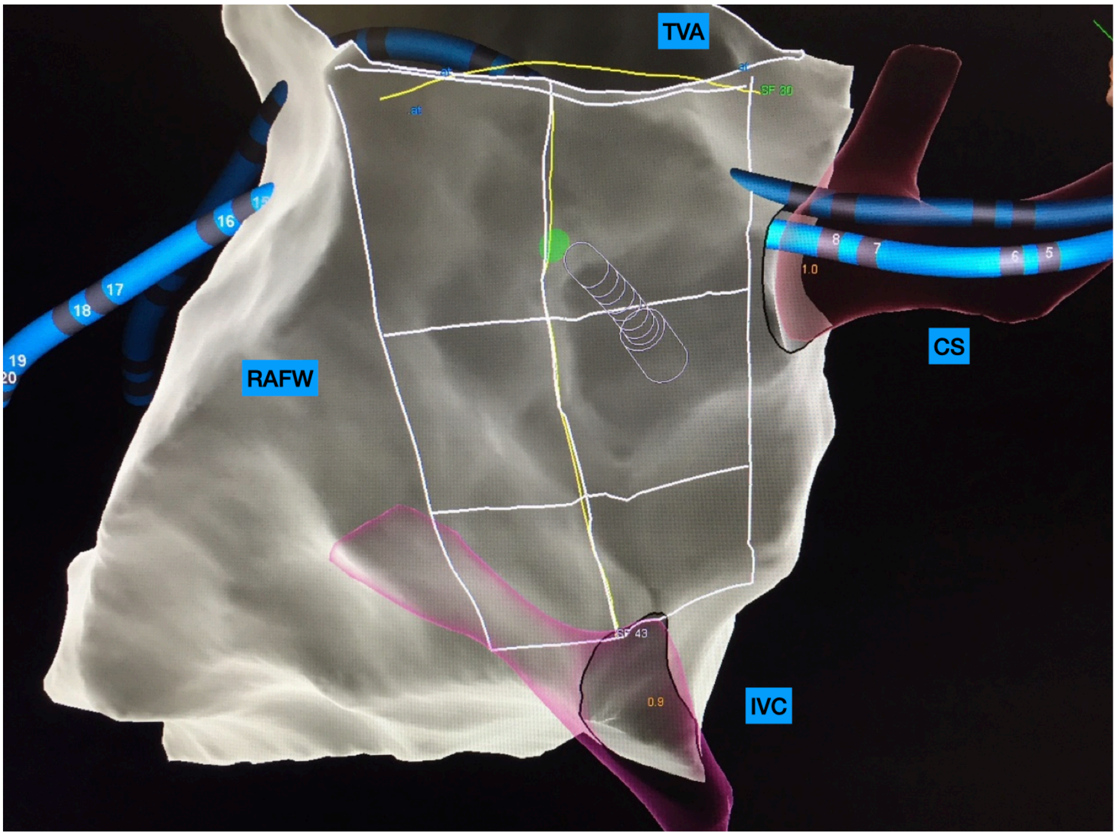


Figure 2

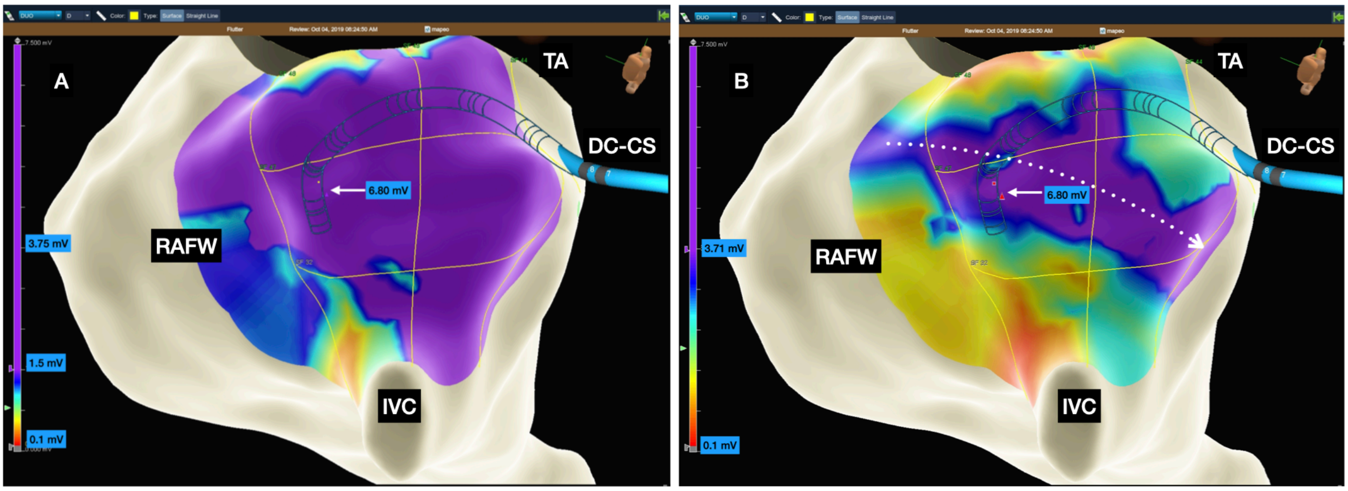
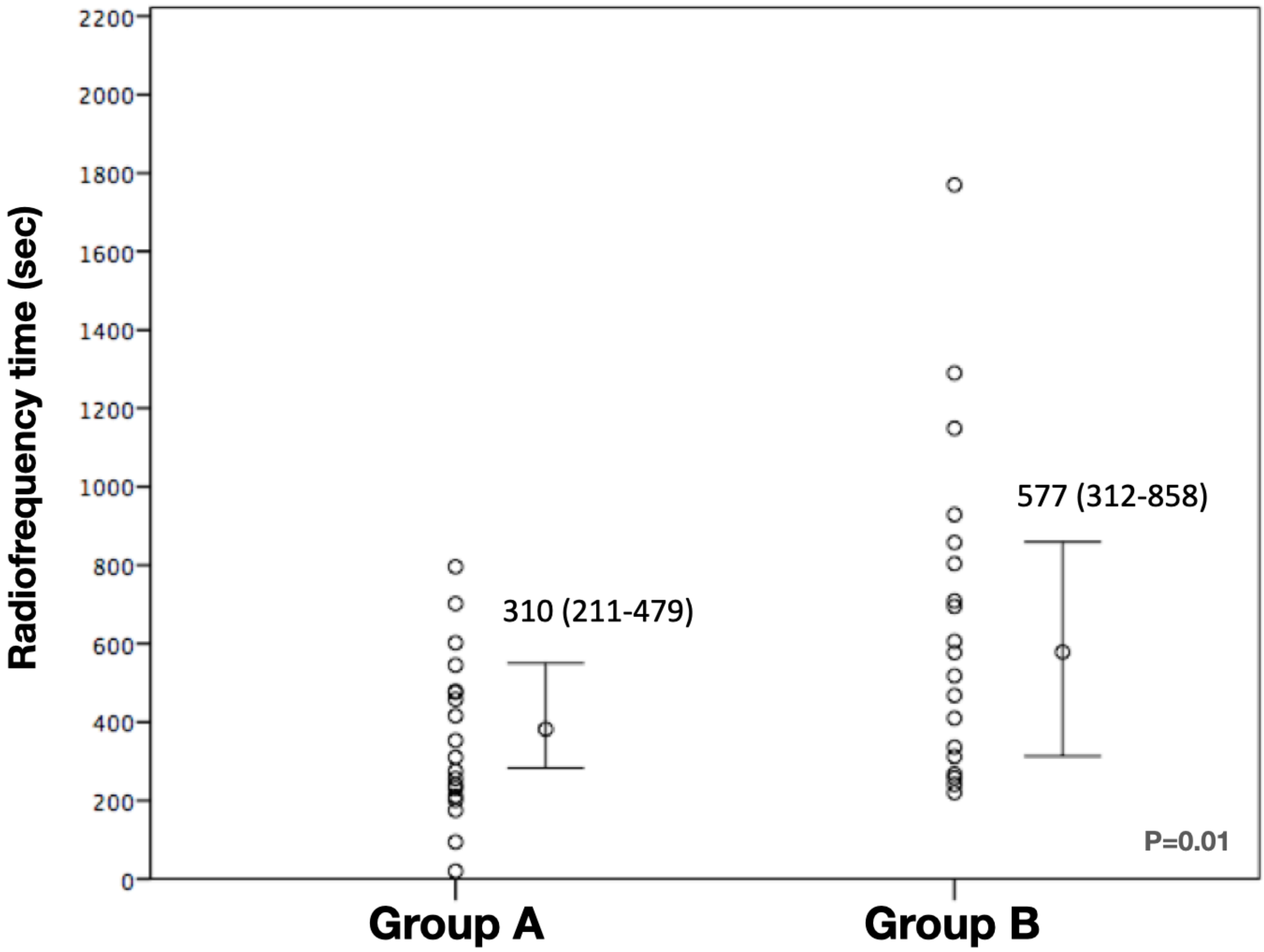
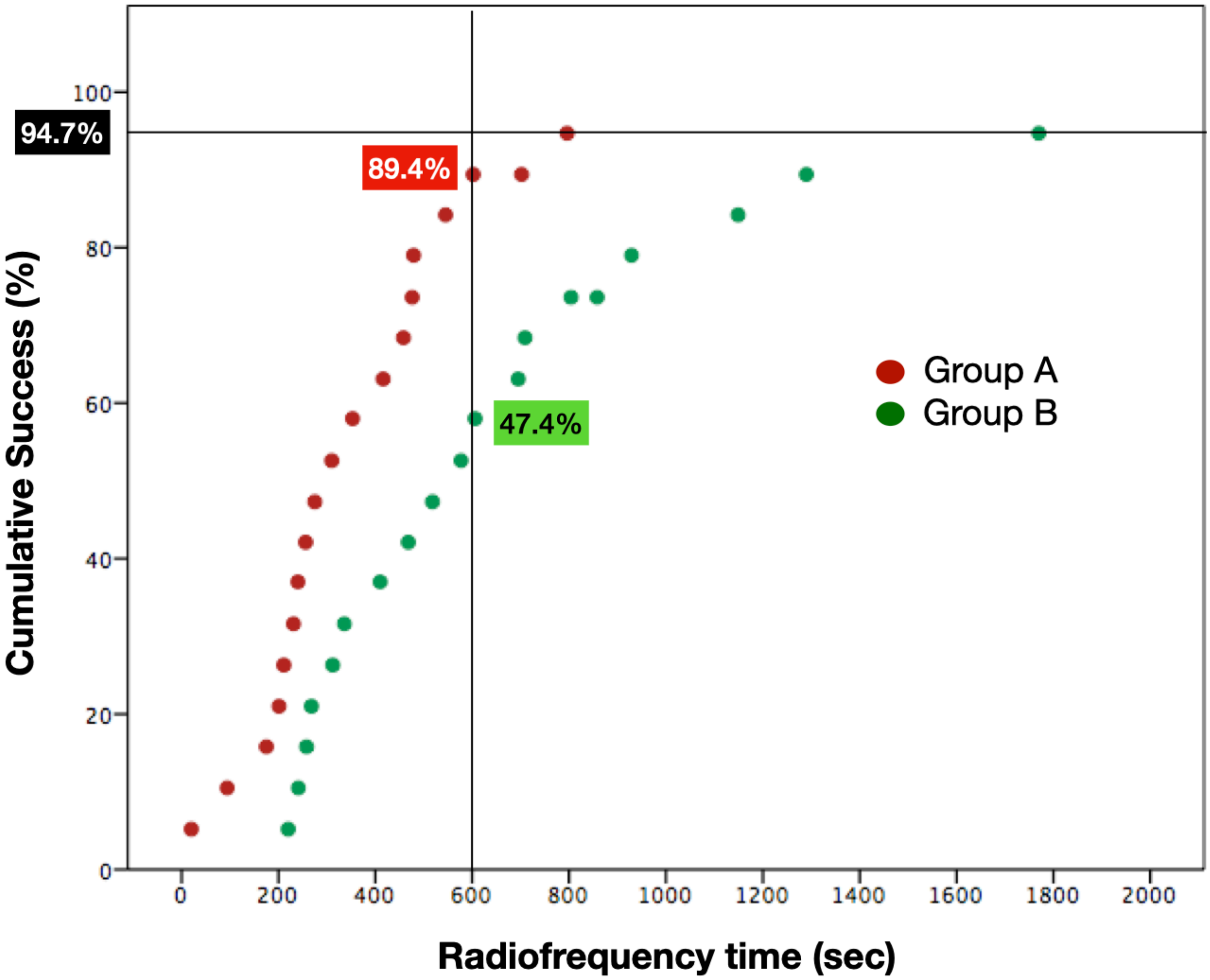

A
TA
DC-CS
RAFW
6.80 mV
3.75 mV
1.5 mV
0.1 mV
IVC
B
TA
DC-CS
RAFW
6.80 mV
3.71 mV
0.1 mV
IVC

Figure 3



Radiofrequency time (sec)
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
310 (211-479)
577 (312-858)
P=0.01
Group A
Group B

Figure 4



Cumulative Success (%)
100
80
60
40
20
0
94.7%
89.4%
47.4%
Group A
Group B
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Radiofrequency time (sec)

Table 1. Baseline patient characteristics.

	Original Cohort			Propensity score-matched cohort		
	Group A n (38)	Group B n (28)	p	Group A n (19)	Group B n (19)	p
Age, years	67.4 (58.5-72.4)	62.4 (55.7-69.5)	0.15	64.3 (58-72.4)	62.2 (55.7-69.6)	0.54
Female sex	2 (5.3)	5 (17.9)	0.12	2 (10.5).	1 (5.3)	1
BMI, kg m^{-2}	28 (24.7-32.5)	30.4 (25.2-33.5)	0.28	29 (24.5-33)	31.1 (26.6-33.8)	0.51
HT	23 (60.5)	12 (42.9)	0.15	9 (47.4)	9 (47.4)	1
Diabetes	14 (36.8)	6 (21.4)	0.18	6 (31.6)	4 (21.1)	0.71
COPD/OSA	8 (21.1)	6 (21.4)	0.97	3 (15.8)	6 (31.6)	0.45
IHD	5 (13.2)	2 (7.1)	0.69	4 (21.1)	2 (10.5)	0.66
DCM	3 (7.9%)	2 (7.1)	0.91	1 (5.3)	2 (10.5)	1
Depressed LVEF	6 (15.8)	7 (53.8)	0.37	2 (10.5)	5 (26.3)	0.4
Dilated LA	28 (73.7)	20 (71.4)	0.84	15 (78.9)	14 (73.7)	1
Dilated RA	18 (62.1)	11 (39.3)	0.51	10 (52.6)	10 (52.6)	1
Previous AF	7 (18.4)	9 (32.1)	0.2	2 (10.5)	4 (21.1)	0.66
Persistent, AFL	16 (42.1)	12 (42.9)	0.95	10 (52.6)	8 (42.1)	0.51

Data are presented as number (%), median (interquartile range)

AFL: atrial flutter; AF: atrial fibrillation; BMI: body mass index; COPD: chronic obstructive pulmonary disease; DCM: dilated cardiomyopathy; HT: hypertension; IHD: ischemic heart disease; LA: left atrium; LVEF: left ventricular ejection fraction; RA: right atrium; OSA: obstructive sleep apnea.

Table 2. Ablation procedure and follow-up data.

	Original Cohort			Propensity score-matched cohort		
	Group A n (38)	Group B n (28)	p	Group A n (19)	Group B n (19)	p
Basal rhythm, AFL	14 (36.8)	10 (35.7)	0.92	10 (52.6)	7 (36.8)	0.32
3D-RA	38 (100)	12 (42.9)	<0.001	19 (100)	9 (47.4)	<0.001
Zero-Fx	38 (100)	23 (82.1)	0.01	19 (100)	14 (73.7)	0.01
Number of RF lesions	13 (7.5-19)	17 (1.2-24.7)	<0.05	14 (9-19)	20 (2-25)	0.085
Contact Force, g	15 (13-20)	12 (10-14)	<0.001	14.5 (13-16.2)	12 (9-14)	<0.01
LSI	5.6 (5-6.1)	4.5 (3.9-4.7)	<0.001	5.3 (4.9-6)	4.5 (4.1-4.7)	<0.001
Long Sheath	4 (10.5)	4 (14.3)	0.71	2 (10.5)	3 (15.8)	1
EPS time, min	62.5 (53-78)	45 (20-55)	<0.001	59 (52-87)	50 (22-58).	<0.01
Ablation time, min	22.6 (11-37)	46 (18-689)	<0.01	22.6 (9-39.6)	45.2 (20-67)	0.064
Total duration, min	105 (90-138)	110 (87-35)	0.91	107.5 (86-143)	114 (95-139)	0.69
RF time, sec	275.5 (186.3-479.5)	540.5 (310-844.5)	<0.001	310 (211-479)	577 (312-858)	0.01
RF time < 120 sec	8 (21.1)	0	0.017	2 (10.5)	0	<0.05
Bidirectional block	37 (97.4)	27 (97.4)	1	18 (94.7)	18 (94.7)	1
Complications	1 (2.6)	0	1	1 (5.3)	0	1
Recurrence	2 (5.3)	1 (3.6)	1	2 (10.5)	1 (5.3)	1

Data are presented as number (%), median (interquartile range)

3D-RA: Tridimensional reconstruction of right atrium, AFL: atrial flutter; EPS: electrophysiologic study; Fx: fluoroscopy; LSI: lesion size index; RF: radiofrequency