The advantage of mini electrode-equipped catheter for the radiofrequency ablation of paroxysmal supraventricular tachycardia

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Abstract

Introduction: Novel ablation catheters equipped with mini-electrodes (ME) offer high resolution mapping for target tissue. This study aimed to evaluate the mapping performance and efficacy of ME catheters in radiofrequency ablation of paroxysmal supraventricular tachycardias (PSVTs). **Methods:** We prospectively enrolled 136 patients who were undergoing catheter ablation of PSVT including 76 patients with atrioventricular nodal reentrant tachycardia (AVNRT) and 60 patients with atrioventricular reentrant tachycardia (AVRT) or Wolff-Parkinson-White (WPW) syndrome. Patients were randomized to the ME group (ablation using a 4.5mm tip ME catheter) or the control group (ablation using a conventional 4mm tip catheter). The number of ablation attempt and cumulative ablation time to ablation endpoints, which was defined as an emergence of junctional rhythm in AVNRT or accessory pathway (AP) block in AVRT/WPW syndrome were compared. **Results:** During ablation procedures, discrete SP or AP electrograms were found in 27 (39.7%) patients in the ME group and 13 (19.1%) patients in the control group. The primary study outcomes were significantly lower in the ME group (ablation attempt number: 2.0 [1–4] vs. 3.0 [2–7] in the ME and control group, p=0.032; ablation time: 23.5 [5.0–111.5] vs. 64.5 [16.0–185.0] seconds, p=0.013). According to the PSVT diagnosis, ablation time to junctional rhythm was significantly shorter in the ME group in AVNRT. In AVRT/WPW syndrome, both ablation attempt number and ablation time to AP block showed trends favoring the ME group. **Conclusion:** The novel ME catheter was advantageous for identifying pathway potentials and reducing initial ablation attempt number and time in PSVT ablation. (ClinicalTrials.gov number, NCT04215640)

Introduction

Paroxysmal supraventricular tachycardia (PSVT) refers to cardiac arrhythmias originating above the ventricle that results in sudden rapid heart rate episodes. More than 90% of PSVTs are atrioventricular nodal reentrant tachycardia (AVNRT), atrioventricular reentrant tachycardia (AVRT) or Wolff-Parkinson-White (WPW) syndrome, which are caused by abnormal electrical extra pathways in heart, including slow pathways (SP) or accessory pathways (AP).[1] Catheter-based radiofrequency ablation (RFA) of these extra pathways is highly effective for the treatment of PSVTs. The procedure is often successful, but sometimes it becomes complicated when accurate localization of SP or AP is difficult.[2] Location of the ablation target is determined based on anatomical markers and electrical potentials, and obtaining adequate electrograms at ablation sites is important for effective ablation of PSVTs.[2, 3]

Mapping resolution of the ablation catheter is dependent on electrode size and spacing. A novel ablation catheter (IntellaTip MiFi OI, Boston Scientific, Boston, MA, USA) has three additional, radially-distributed

mini electrodes (MEs) located 1.3 mm from the distal tip that offer high-resolution electrograms close to ablation sites. The ME-equipped ablation catheter provides more precise localization of the actual ablation site. It has been shown to be helpful to avoid unnecessary radiofrequency application for cavotricuspid isthmus ablation in previous clinical studies.[4, 5] The ME signals visualized in ablation catheter can be advantageous for accurate localization of SP or AP and identification of discrete pathway electrograms during RFA for PSVTs. This study aimed to evaluate the mapping performance and efficacy of novel ablation catheters equipped with MEs compared to conventional ablation catheters, in RFA for AVNRT or AVRT/WPW syndromes.

Methods

Study population

We prospectively enrolled 136 patients who were undergoing radiofrequency catheter ablation for PSVT between January 2020 and June 2021. The study was conducted in two medical centers affiliated with the Catholic Medical Center. Patients with age <15 years and who were scheduled to undergo electrophysiology study for supraventricular tachycardia were screened. For inclusion, any AVNRT, AVRT, or WPW syndrome with atrial fibrillation had to be documented during the electrophysiologic study. The patients in whom supraventricular tachycardia (SVT) was not induced or only atrial tachycardia was induced were excluded. The study was registered in a public trials registry. (ClinicalTrials.gov number, NCT04215640) This study was approved by the Institutional Review Board of Catholic Medical Center. All patients provided written informed consent. No industry or public institution was involved in the design, reporting, or dissemination plans of our research.

Randomization and study protocol

Included patients were categorized into AVNRT or AVRT/WPW syndrome groups according to the induced SVT during procedures. When [?]2 arrhythmias were induced during the same procedure, categorization and data acquisition was based on the first SVT targeted for ablation. Patients were randomized at a 1:1 ratio into the ME group or the control group. Block randomization (block size 4) was used to assign the randomization sequence for each SVT category (AVNRT or AVRT/WPW syndrome) at each site. Patients assigned to the ME group received RFA for induced SVTs using a 4.5mm tip ablation catheter equipped with ME (IntellaTip MiFi OI, Boston Scientific, Boston, MA, USA), which has conventional bipolar electrodes and three additional MEs with irrigation holes at the distal tip (Figure 1A). Patients assigned to the control group received RFA using a 4 mm tip ablation catheter (Blazer II HTD, Boston Scientific, Boston, MA, USA) (Figure 1B).

Electrophysiology study and RFA

All antiarrhythmic drugs were discontinued at least 2 days before the procedure. Diagnostic mapping catheters were inserted through the femoral vein and positioned to the lateral side of the right atrium, coronary sinus, His area, and right ventricular apex. Electrograms were recorded using a digital recording system (CardioLab, GE Healthcare, Chicago, IL, USA). At baseline, ventricular and atrial programmed stimuli were delivered to identify the presence of AP and/or SP. If SVT was not induced, atrial and ventricular programmed stimuli were delivered again after intravenous isoproterenol infusion. Once SVT was induced, His-refractory ventricular premature beat was delivered and overdrive pacing from the right ventricular apex was performed. Differential diagnosis of the SVT was mainly based on the following criteria:

1) AVNRT: Absence of reset response to His-refractory ventricular premature beat and corrected post-pacing interval > 110ms after right ventricular overdrive pacing.

2) AVRT: Presence of AP on baseline study, positive reset response to His-refractory ventricular premature beat, and corrected post-pacing interval < 110 ms after right ventricular overdrive pacing.

If SVT was not sustained to complete above studies or the responses were conflicting, further studies to differentiate SVT were attempted including para-Hisian pacing, ventricular differential pacing and/or the

assessment of [?]AH during sinus rhythm and SVT. After SVT diagnosis, the ablation catheters were advanced via femoral vein using long sheaths. RFA was performed targeting SP potentials in AVNRT or AP potentials in AVRT/WPW syndrome. When it was difficult to map the pathway potentials, RF energy was delivered to an anatomically expected SP location in AVNRT, and to a site showing earliest atrial activation during ventricular pacing in AVRT. In WPW syndrome with an absence of retrograde conduction via AP, a site with an earliest preexcited ventricular activation was targeted for ablation. In patients who were assigned to the ME group, three bipolar ME signals made between m1-2, m2-3, and m3-1 were shown in addition to conventional bipolar and unipolar electrograms at the distal ablation tip. Ablation was performed with a guidance of the ME signals. The radiofrequency (RF) generator was set at the non-irrigation mode in both groups, but minimal (2 mL/minute) saline irrigation was performed for the ME catheters to maintain patency. In AVNRT, the primary ablation endpoint was the emergence of junctional rhythm during ablation. In AVRT/WPW syndrome, the primary ablation endpoint was a conduction block of targeted AP. When the ablation endpoint was not achieved within 10 to 20 seconds of ablation, ablation was stopped, and repeated mapping was performed to find the optimal ablation site. Temperature controlled RF delivery with a target temperature of 60°C was performed with an initial power of 25W for SP ablation and 35W for AP ablation in both groups. When the primary ablation endpoint was achieved, RF power was gradually increased to 35 to 40W and the ablation was continued for 50 to 60 seconds. After successful initial RF energy delivery, consolidation ablation was performed at the operator's discretion. SVT non-inducibility was confirmed using atrial and ventricular programmed stimulus maneuvers after a 20-minute waiting period. The procedure endpoint was [?]1 atrioventricular nodal echo beat during atrial programmed stimuli in AVNRT. In AVRT/WPW syndrome, the procedure endpoint was an absence of AP conduction at rest and after intravenous 12mg bolus injection of adenosine.

Study outcome definitions

To compare the mapping performance, the rate of discrete pathway electrogram identification at the ablation catheter was analyzed. The primary study outcomes were RF attempt number and cumulative ablation time to achieve the first ablation endpoint, which was defined as an emergence of junctional rhythm in AVNRT or AP block in AVRT/WPW syndrome. When multiple RFAs were needed to achieve the ablation endpoint, the ablation time to endpoint was defined as the sum of all ablation time spent during ineffective and effective ablation before achieving the endpoint. The secondary study outcomes were total ablation time, average RF power, average temperature, procedure time, acute SVT reinduction rate and dormant AP conduction rate. If [?]2 SVTs were induced or [?]2 APs were targeted for ablation in a single procedure, we recorded the study outcomes of the first ablated SVT or AP. All study outcomes were recorded during the index procedures.

Statistical analysis

Normally distributed continuous variables are presented as the mean ± standard deviation for normally distributed values and compared using Student's t-tests. Non-normally distributed continuous variables are presented as the median (25^{th} – 75^{th} percentiles) and compared using Mann-Whitney U tests. Categorical variables are presented as the frequency with percentage (%) and were compared using chi-square or Fisher's exact tests. All analyses were two-tailed, and a p-value <0.05 was considered statistically significant. All statistical analyses were performed using R version 3.6.2 (R Foundation).

Results

Baseline characteristics

A total of 136 patients were included in the study and 68 patients were each allocated in the ME group and the control group. According to SVT diagnosis, there were 76 patients with AVNRT (38 in the ME group and 38 in the control group) and 60 patients with AVRT/WPW syndrome (30 in the ME group and 30 in the control group). The mean age was 51.2 (±16.7) years and 76 (55.9%) patients were male (Table 1). There was no significant difference in demographic characteristics or underlying comorbidities between the ME group and the control group.

Procedure outcomes in the entire population

Ablation procedures were successfully conducted in all patients with no intraprocedural complication. There was no crossover in ablation catheters during the procedures. RF attempt number to achieve the prespecified ablation endpoints was significantly lower in the ME group compared to the control group (2 [1–4] vs. 3 [2–7] in the ME group and the control group, respectively, p=0.032). RFA time to the ablation endpoints was also significantly shorter in the ME group (23.5 [5.0–111.5] vs. 64.5 [16.0–185.0] seconds in the ME group and the control group, respectively, p=0.013) (Table 2). During the entire procedure, total ablation time and procedure time were similar between the two groups. Average RF power was higher in the ME group (34.0 [31.0–38.0]W vs. 32.0 [28.0–33.5]W, p<0.001) and average temperature was lower in the ME group (41.0 [34.0–42.0]°C vs. 49.0 (46.0–51.5)°C, p<0.001). There was no significant difference in the acute SVT reinduction rate between the two groups (5.9% vs. 5.9%). The procedure endpoint ([?]1 echo beat or an absence of AP conduction) was achieved by repeated ablation in all patients with SVT reinduction.

Outcomes in AVNRT

SP ablation was performed in 76 patients with AVNRT. Eight patients had atypical AVNRT without significant difference between the two groups (Table 3). Median RF attempt number to the emergence of junctional rhythm was 2 (1–4) in the ME group and 2 (2–4) in the control group (p=0.113) (Table 3). Median ablation time to the emergence of junctional rhythm was 16 (5–80) seconds in the ME group and 48 (16–144) seconds in the control group (p=0.043). There was no significant difference in total ablation time, procedure time, or acute AVNRT reinduction rates between the two groups. Discrete SP electrograms were observed via ablation catheter in 14/38 (36.8%) patients in the ME group and 6/38 (15.7%) patients in the control group (Figure 2A). There was no transient or persistent atrioventricular block after ablation in all subjects.

Outcomes in AVRT/WPW syndrome

AP ablation was performed in 60 patients with AVRT/WPW syndrome. Manifest AP was shown in 18 patients without significant difference between the two groups (Table 4). Median RF attempt number to AP block was 2.5 (1–5) in the ME group and 4 (2–9) in the control group (p=0.128). Median ablation time to AP block was 29 (3–123) seconds in the ME group and 82.5 (16–214) seconds in the control group (p=0.110) (Table 4). There was no significant difference in total ablation time or procedure time. SVT reinduction was not observed in all patients, and acute AP reconnection rate (23.3% vs. 20.0% in the ME group and the control group, respectively, p=1.000) and dormant AP conduction rate (10.0% vs. 6.7%, p=1.000) were not significantly different between the two groups. Discrete AP electrograms were observed via ablation catheter in 13/30 (43.3%) patients in the ME group and 7/30 (23.3%) patients in the control group (Figure 2B, 2C, 2D).

Discussion

Our study demonstrated the efficacy of new ablation catheters equipped with MEs compared to conventional ablation catheters in RFA of PSVTs. The ME catheter was advantageous to the conventional ablation catheter in terms of the number of RF attempts and RFA time to achieve effective ablation endpoints. The advantage of the ME catheter was shown for both SP and AP ablation, although the difference of the primary study outcomes did not reach statistical significance when analyzed separately. Notably, the ME catheter was more than twice as effective in visualization of the pathway electrograms as the conventional ablation catheter (27/68 vs. 13/68). However, the overall procedure results were successful in all patients without a significant difference in total procedure time or acute SVT reinduction rates.

High-density mapping catheters enable the precise identification of local electrical signals with minimization of far-field signals and background noise that confers higher resolution mapping in low-voltage zones and scar areas.[6, 7] Currently, high-resolution electroanatomical mapping is widely used in catheter ablation of ventricular tachycardias and atrial arrhythmias.[8-11]The IntellaTip MIFI OI catheter is an ablation catheter that shows only three additional bipolar ME signals. This catheter may not be suitable to map the entire arrhythmia circuit in detail, but it can help to accurately localize catheter tip and to assess ablated and

viable tissue. Previous clinical studies showed that the ablation catheter equipped with ME was effective in the visualization of local gaps and avoiding unnecessary ablation during RFA of CTI and ATs.[4, 5, 12] However, Iwasawa et al. reported that the ME catheter showed worse efficacy compared to the conventional ablation catheters for CTI ablation in a prospective clinical study. The ME catheter group had higher RF application numbers and longer ablation time compared to the 8 mm dumbbell-shaped irrigated-tip catheter or cryothermal catheter group.[13] In that study, there was a significant difference in the average RF power between the ME group and conventional ablation catheter group (31.3 +- 9.1W vs. 38.6 +- 7.6W in the ME and conventional ablation catheter group, respectively). For CTI ablation, effective transmural lesion formation would be more important than precise electroanatomical mapping. Although the ME signal showed viable ablation targets and signal attenuation after ablation, the temperature-controlled ablation via the small electrode may have resulted in less RF power and shallow ablated lesions compared to the irrigated tip ablation catheter. In contrast, RFA of PSVT requires relatively less power delivery, and detailed mapping with accurate localization of the ablation target is a more important factor for a successful procedure.[1, 2] Our study first showed that use of a high-resolution ablation catheter can be helpful in RFA for PSVTs. The ME catheter showed improved ability to identify pathway potentials, as well as to localize actual ablation site. SP or AP potentials are often small and unclear in large electrodes, because it can be overlapped with far-field atrial and ventricular electrograms. In our study, ME catheters were highly effective in the recognition of pathway electrograms (overall 39.7%), compared to the conventional bipolar ablation catheter (overall 19.1%). The higher effectiveness of MEs in differentiating pathway potentials is most likely to have driven the difference in the primary study outcomes.

It is important to point out that the ME groups showed higher average RF power and lower average temperature in total ablation parameters, despite identical RF generator setting in the two groups. Because the IntellaTip MiFi OI catheter was an irrigated-tip catheter, continuous saline infusion was required to maintain patency. Although the flow rate was minimalized (2 mL/min) to balance with the Blazer II HTD catheter which has no irrigation function, it may have affected the temperature sensed in the ablation tip that would result in altered temperature-controlled RF power delivery. Irrigated-tip catheter ablation has been shown to be more effective in AP ablation via increased power delivery, but previous studies mostly reported that increased efficacy was observed when more than 17 mL/min of saline irrigation was applied.[14, 15] With the minimal irrigation in our study, initial RF efficacy does not seem to have been largely influenced by this difference. Even if the difference in RF power contributed to the initial ablation time, it would have little effect on ablation attempt number to achieve ablation endpoint, which mostly depends on the accuracy of ablation location rather than the speed of RF energy rising. Traditionally, irrigation mode is not preferred in AVNRT ablation due to the risk of atrioventricular nodal injury but irrigated-tip ablation is occasionally used in complex AP ablation. The use of ME catheters with moderate saline irrigation could more improve RF efficacy in AVRT/WPW syndrome.

Limitation

The operators could not be blinded to the ablation catheters used, and awareness of the study group may have biased the study results. Although the primary outcomes were significantly different between the two groups in the entire population, the study did not have enough power to validate statistical significance in the AVNRT population or the AVRT/WPW syndrome population alone. However, there were similar trends favoring the ME catheters in both the AVNRT and AVRT/WPW syndrome groups. As discussed above, although we minimalized the irrigation flow rate in the ME group, it could have affected the ablation efficacy, especially for the initial ablation time to achieve the ablation endpoints.

Conclusion

This prospective, randomized controlled study demonstrated that novel ablation catheter equipped with MEs was advantageous for reducing the number of RF attempts and initial ablation time to achieve effective ablation endpoints for AVNRT or AVRT/WPW syndrome. High-resolution mapping with improved efficacy to visualize pathway potentials by MEs would be helpful for precise localization of ablation target in RFA of PSVTs.

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Figure legends

Figure 1. Ablation catheters used in the study.

A) IntellaTip MiFi OI catheter equipped with three mini-electrodes (large arrow) and irrigation holes (small arrow) at distal tip. B) Blazer II HTD catheter.

Figure 2. Discrete pathway electrograms in ME catheters.

A) SP electrograms in MEs (small arrows), B) Right posteroseptal AP electrograms during ventricular pacing in distal ablation electrodes (large arrow) and MEs (small arrows), C) AP electrograms in MEs during preexcitation via left lateral AP (small arrows), D) Left lateral AP electrograms in MEs during AVRT (small arrows).

ME = mini electrode; SP = slow pathway; AP = accessory pathway; AVRT = atrioventricular reentrant tachycardia.

Table 1. Baseline characteristics in the two groups

	ME group (N=68)	Control group (N=68)	p
Age (years)	50.5 ± 16.3	51.9 ± 17.2	0.628
Male sex	41 (60.3%)	35 (51.5%)	0.388
Hypertension	17 (25.0%)	20 (29.4%)	0.700
Diabetes	7 (10.3%)	9 (13.2%)	0.790
Heart failure	2 (2.9%)	2 (2.9%)	1.000
Coronary artery disease	1 (1.5%)	2 (2.9%)	1.000
Atrial fibrillation	4 (5.9%)	3 (4.4%)	1.000
Stroke	2 (2.9%)	2 (2.9%)	1.000
Diagnosis			
AVNRT	38 (55.9%)	38 (55.9%)	
AVRT/WPW	30 (44.1%)	30 (44.1%)	

Categorical variables are presented as number (percentages) and continuous variables are presented as the mean ± standard deviation. $p<0.05$ indicates statistical significance.

ME = mini electrode; AVNRT = atrioventricular nodal reentrant tachycardia; AVRT = atrioventricular reentrant tachycardia; WPW = Wolff-Parkinson-White Syndrome

Table 2. Procedure outcomes in the entire population

	ME group (N=68)	Control group (N=68)	p
RF attempt number to the endpoints	2 (1 – 4)	3 (2 – 7)	0.032
Ablation time to the endpoints (sec)	23.5 (5.0 – 111.5)	64.5 (16.0 – 185.0)	0.013
Total ablation time (sec)	187 (136 – 383)	218 (132 – 357)	0.943
Average power (W)	34.0 (31.0 – 38.0)	32.0 (28.0 – 33.5)	<0.001
Average temperature (°C)	41.0 (34.0 – 42.0)	49.0 (46.0 – 51.5)	<0.001
Procedure time (min)	65 (60 – 70)	60 (60 – 70)	0.254
Acute SVT reinduction, n (%)	4 (5.9%)	4 (5.9%)	1.000
Discrete pathway potential visualization, n (%)	27 (39.7%)	13 (19.1%)	0.014

Categorical variables are presented as number (percentages) and continuous variables are presented as the median (25^{th}– 75^{th} percentile). $p<0.05$ indicates statistical significance.

ME = mini electrode; RF = radiofrequency; SVT = supraventricular tachycardia

Table 3. SVT characteristics and procedure outcomes in AVNRT

	ME group (N=38)	Control group (N=38)	p
RF attempt number to junctional rhythm	2 (1 – 4)	2 (2 – 4)	0.113
Ablation time to junctional rhythm (sec)	16 (5 – 80)	48 (16 – 144)	0.043

	ME group (N=38)	Control group (N=38)	p
Total ablation time (sec)	163 (127 – 346)	246 (170 – 350)	0.275
Average power (W)	33 (31 – 35)	30 (27 – 33)	0.007
Average temperature (°C)	41 (39 – 43)	49 (47 – 51)	<0.001
Procedure time (min)	60 (60 – 70)	60 (55 – 70)	0.281
Acute SVT reinduction, n (%)	4 (10.5%)	4 (10.5%)	1.000
SP potential visualization, n (%)	14 (36.8%)	6 (15.7%)	0.068
Atypical AVNRT, n (%)	5 (13.1%)	3 (7.9%)	0.436

Categorical variables are presented as number (percentages) and continuous variables are presented as the median (25^{th}– 75^{th} percentile). $p<0.05$ indicates statistical significance.

AVNRT = atrioventricular nodal reentrant tachycardia; ME = mini electrode; RF = radiofrequency; SVT = supraventricular tachycardia; SP = slow pathway

Table 4. Procedure outcomes in AVRT/WPW syndromes

	ME group (N=30)	Control group (N=30)	p
RF attempt number to AP block	2.5 (1 – 5)	4 (2 – 9)	0.128
Ablation time to AP block (sec)	29 (3 – 123)	82.5 (16 – 214)	0.110
Total ablation time (sec)	206 (152 – 386)	170 (131 – 358)	0.158
Average power (W)	36.2 ± 3.6	32.8 ± 4.5	0.002
Average temperature (°C)	35 (30 – 41)	49 (45 – 52)	<0.001
Procedure time (min)	70 (60 – 80)	61 (60 – 90)	0.631
Acute SVT reinduction, n	0	0	1.000
Acute AP reconnection, n (%)	7 (23.3%)	6 (20.0%)	1.000
Dormant AP conduction, n (%)	3 (10.0%)	2 (6.7%)	1.000
AP potential visualization, n (%)	13 (43.3%)	7 (23.3%)	0.171
Manifest AP, n (%)	10 (33.3%)	8 (26.7%)	0.778
AP location, n (%)			
Left lateral	11 (36.6%)	12 (40.0%)	
Left posterior	6 (20.0%)	9 (30.0%)	
Left anterolateral	4 (13.3%)	5 (16.6%)	
Right lateral	2 (6.6%)		
Right posterior	1 (3.3%)	1 (3.3%)	
Septal	5 (16.6%)	3 (10.0%)	
Epicardial (MCV)	1 (3.3%)		

Categorical variables are presented as number (percentages) and continuous variables are presented as the median (25^{th}– 75^{th} percentile). $p<0.05$ indicates statistical significance.

AVRT = atrioventricular reentrant tachycardia; WPW = Wolff-Parkinson-White; ME = mini electrode; RF = radiofrequency; AP = accessory pathway; SVT = supraventricular tachycardia; MCV = middle cardiac vein