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ORIGINAL ARTICLE

Irrigated Radiofrequency Catheter Ablation with Limited Fluoroscopy for Ventricular Arrhythmias in Children and Adolescents

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Abstract

Background: There are insufficient studies regarding the use of irrigated catheters for ventricular arrhythmia ablations in pediatric patients; therefore, most of the information on this subject has been obtained from studies conducted with adults.

Objective: This study aimed to assess the outcomes of irrigated catheter ablations performed using limited or zero fluoroscopy with the guidance of a three-dimensional electroanatomic mapping system in a pediatric ventricular arrhythmia patient group.

Methods: Thirty-nine consecutive pediatric patients undergoing irrigated catheter ventricular arrhythmia ablations at a single tertiary center were enrolled in this study. All of the children underwent electrophysiological studies using EnSite NavX system guidance with limited or zero fluoroscopy. The ventricular arrhythmia ablations were performed using irrigated catheters in all of the patients.

Results: The mean age of the patients was 12 years old (range = 3.5–17 years) and the mean weight was 50 kg (range = 12–84 kg). The mean procedure time was 165 ± 53 minutes. No fluoroscopy was used in most of the patients (30/39, 77%), and acute success was achieved in 35 patients (89.7%). During a mean follow-up period of 26.7 ± 13.7 months, ventricular arrhythmias recurred in nine patients. Four of these patients underwent successful ablations again and remaining five were followed-up with medical therapy without problems. No complications were seen.

Conclusion: Ventricular arrhythmia ablations can be performed safely and effectively using irrigated catheters in pediatric patients. In addition, successful radiofrequency ablations can be achieved using three-dimensional electroanatomic mapping system without fluoroscopy in most patients.

Keywords: children; open irrigated-tip catheter; three-dimensional electroanatomic mapping system; ventricular arrhythmia

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Catheter ablations have been introduced as an effective method with an acceptable complication rate for the treatment of ventricular arrhythmias (VAs) in children and adolescents. However, the success rate obtained with VA catheter ablations is lower than that achieved in supraventricular arrhythmias.[1-4]

The presence of deeper foci is one of the reason of ablation failure.[5] Radiofrequency ablation (RFA) with irrigated tip catheters enables the formation of deeper and more extensive lesions, thereby increasing the success rate.[6-7] Unfortunately, there is very limited experience in the use of an irrigated tip ablation catheter in the pediatric population, and the literature is scarce in the use of this catheter in pediatric VA patients.

This study presents the experiences of RFAs performed in pediatric and adolescent patients with VAs [ventricular tachycardia (VT), premature ventricular contraction (PVC)] using irrigated catheters via the guidance of a three-dimensional electroanatomic mapping system (3DMS) with zero or limited fluoroscopy in an electrophysiology center.

Methods

Study population

This single-center retrospective study included pediatric patients under 18 years old who underwent catheter ablations using open irrigated tip catheters (OITCs) (Cool Flex, 4 mm, 7F; Abbott/St. Jude Medical Inc., St. Paul, MN, USA) with the guidance of 3DMS (EnSite NavX system; Abbott/St. Jude Medical Inc.) due to VAs between July 2012 and March 2018.

The patients' clinical features (history, prior medications, and treatments), physical examinations, electrocardiograms (ECGs), echocardiograms (ECHOs), Holter monitorings, ablation procedures, outcomes, complications, and follow-ups were evaluated.

Electrophysiologic study, mapping, and ablation

The antiarrhythmic medications were withdrawn for a period of at least 5 half-lives. After receiving written consent from the patient's parents, an electrophysiological study (EPS) and catheter ablation procedure were begun. The EPS and catheter ablation were performed under mild or deep sedation with local anesthesia, as long as the patient's status was convenient, in order to preserve the VA. Therefore, the anesthetic level was adjusted according to the tolerance of the child and whether the arrhythmia was suppressed or not. The EPS started with the insertion of one sheath from the right femoral vein and one from the left femoral vein, and the endocardial right atrium and coronary sinus geometry were created with 3DMS guidance, without using fluoroscopy. The superior vena cava, His potential, and inferior vena cava were marked on the right atrium map. After the basic measurements (atrium-His interval, His-ventricle interval, PR-QRS-QT durations, basic cycle length, and Wenckebach point) were evaluated, the induction of tachycardia was attempted via extrastimulation and burst pacing from the right atrium and right ventricle, with or without intravenous metaproterenol sulfate and/or dobutamine provocation.

The radiofrequency (RF) lesions were created in the power-control mode with powers of 30 and 35 watts using an RF generator (Atakr II; Medtronic Inc., Minneapolis, MN, USA). When the RF was administered, the delivered power, impedance, and catheter temperature were recorded continuously. The RF energy was delivered at a target duration of 30 or 60 seconds. Two types of saline irrigation were carried out using a peristaltic pump (Cool Point; Abbott/St. Jude Medical Inc.) at 17 ml/min during the RF energy administration and at 2 ml/min without the RF energy. When a left ventricular-originating VA was determined, a femoral artery puncture was performed to carry out the retroaortic approach. The ablation and diagnostic catheters were introduced to the left ventricle retrogradely for mapping and ablation by means of fluoroscopy. In addition, fluoroscopy was also used in the evaluation of the association between the point selected as the RFA target in a left-sided VA and the coronary arteries. When a left-sided ablation was performed, 70 units/kg of heparin (with a maximum of 5000 units) was intravenously administered.

The programmed/incremental stimulation was carried out from the atrium and ventricle, with and without metaproterenol and/or dobutamine, 30 minutes after the final ablation. Acute procedure success was defined as no further inducible or spontaneous VT/PVC for 30 minutes after the final ablation lesion. (n=31/39) When the PVCs could not be completely eliminated after the PVC ablation, if the PVC burden decreased more than 50% by Holter monitoring performed the next day (n=4/39), the ablation was accepted as successful.

After the procedures, the patients were followed-up for one night under continuous cardiac monitoring. Each of the patients underwent an ECHO, 12-lead ECG, and 24-hour Holter monitoring before they were discharged. Those patients who underwent left-sided ablations were given 3–5 mg/kg of oral acetylsalicylic acid for 1 month. The outpatient follow-ups were scheduled for 1 month, 6 months, and yearly.

Statistical analysis

The data were analyzed using the Statistical Package for the Social Sciences version 17.0 (SPSS Inc., Chicago, IL, USA). They were present-

ed as the count (%), mean ± standard deviation, and median ± interquartile range, as appropriate. The distribution of the variables was analyzed using the Kolmogorov-Smirnov test. The group comparisons were performed with a one-way analysis of variance. A p value of 0.05 was considered to be statistically significant.

Results

A total of 39 patients (25 PVCs, 14 VTs, 18 females) with a mean age of 12.08 years old (range = 3.5–17 years) who underwent RFAs with OITCs due to VAs were included in this study. The arrhythmogenic origin was the right side in 33 patients and the left side in 6 patients. The demographic and clinical characteristics of the patients are presented in Table 1. Eight patients had failed ablation histories in another center, and 25 patients were receiving at least one antiarrhythmic medical treatment. The most common complaint was palpitation, but 9 patients were completely asymptomatic. Ablations were performed in three of the patients due to mild left ventricular dysfunction, which was thought to be associated with a VA, despite medical treatment. PVC triggered polymorphic ventricular tachycardia and implantable cardioverter defibrillator (ICD) storm were found in one 14-year-old girl who was followed-up with an ICD implanted due to the diagnosis of long QT. Also, many ICD shocks to true VTs were determined in the ICD recordings of this patient. ICD storm could not be completely controlled medically and so successful PVC ablation was performed.

The ablation procedures failed in 4 of the patients (10.2%), all of whom were VT patients. In 4 patients with right ventricular outflow tract (RVOT) originating PVCs, PVC burden was decreased more than 50% by Holter monitoring performed the next day. In remaining 31 patients VAs were completely eliminated by ablation. The acute success rate was 89.7%. Each of the 4 patients with failed ablations are being followed-up with single or combined antiarrhythmic medical treatments. During the follow-up, the cardiac functions of the patients who developed dilated cardiomyopathy and mild left ventricular dysfunction normalized after their successful ablations.

The patients' procedural data is presented in Tables 2 and 3. The procedure time was longer in those patients undergoing VA ablations than in those undergoing PVC ablations (194 ± 60.3 min and 148.8 ± 41.4 min, respectively, p = 0.01). Similarly, the average and maximal temperatures were higher in the VT ablations. When the patients were evaluated according to their previous ablation histories, the maximum deflection index (MDI) was higher in the patients referred to our clinic from an outer center due to a failed VA ablation attempt than in the

Table 1. Characteristics of all study participants.

Characteristics	**Patients** (n= 39)
Age (mean ± SD, years)	12.1 ± 3.0
Sex (n, female/male)	18/21
Weight (mean ± SD, kg)	49.8 ± 14.6
Height (mean ± SD, cm)	152.4 ± 18.6
Symptoms (n)	
Asymptomatic	9
Dyspnea	1
Pre-syncope	2
Chest pain	5
Palpitation	22
Syncope	3
PVC load (mean ± SD, %)	27.0 ± 10.0
Heart disease, n (%)	9/39 (23%) *
PVC/VT (n)	25/14
Echocardiography	
SF (mean ± SD, %)	35.7 ± 4.74
LVEDD (mean ± SD mm)	44.5 ± 5.58
IVSD (mean ± SD mm)	7.83 ± 1.56
Prior Therapy, (n)	
No (n)	14
Yes (n)	25
Medical (n)	25
Propranolol	8
Metoprolol	13
Verapamil	3
Sotalol	4
Propafenone	3
Flecainide	3
Ablation (n)	8

Values are given as count, % or mean ± SD as appropriate.

IVSD, interventricular septum diastolic dimension; LVEDD, left ventricular end diastolic dimension; PVC, premature ventricular complex; SF, shortening fraction; VT, ventricular tachycardia

* 3 mild left ventricular dysfunction, 1 mild mitral insufficiency, 1 medically controlled dilated cardiomyopathy, 1 small ventricular septal defect, 1 arrhythmogenic right ventricular dysplasia, 1 long QT, and 1 operated atrial septal defect

Table 2. Characteristics of all electrophysiologic studies and ablations

Electrophysiologic properties	**Patients** (n=39)	**Range**
AH (ms, mean ± SD)	67.7 ± 14.8	(42-106)
HV (ms, mean ± SD)	45.2 ± 8.1	(32-72)
BCL (ms, mean ± SD)	729.0 ± 166.9	(480-1140)
PR (ms, mean ± SD)	133.0 ± 18.0	(100-170)
QRS (ms, mean ± SD)	78.3 ± 11.5	(55-110)
QT (ms, mean ± SD)	351.8 ± 32.3	(300-430)
WCL (ms, mean ± SD)	336.8 ± 67.0	(240-550)
Ablation Properties		
Power		
Average (W, mean ± SD)	25.2 ± 8.3	(5-41)
Maximum (W, median, 25th and 75th IQR)	35 (30-35)	(10-50)
Temperature		
Average (°C, median, 25th and 75th IQR)	33 (30-36)	(26-57)
Maximum (°C, median, 25th and 75th IQR)	34 (31-42)	(27-68)
Energy		
Average (joule, mean ± SD)	968.0 ± 650.3	(58-2858)
RF lesion (n)	9.6 ± 5.9	(1-25)
Procedure time (min, mean ± SD)	165.0 ± 53.0	(80-317)
Acute success (n, %)	35/39 (89.7%) *	
Recurrence rate (n, %)	9/39 (23%) **	
Follow-up duration (months)	26.7 ± 13.7	(3-66)

Values are given as median with interquartile range, or mean ± SD as appropriate.

AH, atrium-His interval; BCL, baseline cycle length; °C, centigrade Celsius; HV, His-ventricular interval; IQR, interquartile range; RF, radiofrequency; SD, standard deviation; W, watts; WCL, Wenckebach cycle length

*The VAs were eliminated completely in 31 patients. In 4 patients RVOT originating PVCs, PVC burden was decreased more than 50% by Holter monitoring performed in the next day. The procedures failed in 4 VT patients.

**Four patients who developed recurrences underwent successful repeat ablations and, 3 patients were followed-up with medical therapy without problems. The ablations could not be performed in 2 of the patients because the arrhythmic origin was closely associated with the coronary artery in the repeat study.

Table 3. Achieved ablation parameters during ablation with irrigated tip catheter according to the ventricular arrhythmia type

Ablation properties	**VT** (n=14)	**PVC** (n=25)	***p***
RF lesion (n, mean ± SD)	11.4 ± 8.5	8.5 ± 5.9	0.1
Power			
Average (W, mean ± SD)	22.8 ± 10.2	26.4 ± 6.8	0.2
Maximum (W, median, 25th and 75th IQR)	35.0 (24.3-41.5)	35.0 (30.0-35.0)	0.9
Temperature			
Average (°C, median, 25th and 75th IQR)	34.5 (31.0-53.3)	32.0 (29.5-35.0)	0.04*
Maximum (°C, median, 25th and 75th IQR)	37.0 (32.8-60.3)	32.0 (31.0-38.0)	0.03*
Energy			
Average (joule, mean ± SD)	859.4 ± 659.0	1028.9 ± 651.0	0.4
Procedure time (min, mean ± SD)	194.0 ± 60.3	148.8 ± 41.4	0.01*

Values are given as median with interquartile range, or mean ± SD as appropriate.

°C, centigrade Celsius; IQR, interquartile range; PVC, premature ventricular complex; RF, radiofrequency; SD, standard deviation; VT, ventricular tachycardia; W, watts

*$p<0.05$

Table 4. Properties of ablations according to history of prior ablation

Property	**Prior ablation** (n=8)	**No prior ablation** (n=31)	***p***
RF lesion (n, mean ± SD)	11.7 ± 5.4	9.0 ± 5.9	0.2
Procedure time (min, mean ± SD)	195.8 ± 69.7	157.0 ± 45.9	0.06
MDI (%, mean ± SD)	0.69 ± 0.15	0.51 ± 0.12	0.002*
Average temperature (°C, median, 25th and 75th IQR)	34.5 (29.5-49.3)	33.0 (30.0-36.0)	0.55
Average power (W, mean ± SD)	23.4 ± 11.2	25.6 ± 7.6	0.5
Energy (joule, mean ± SD)	818.3 ± 773.2	1006.7 ± 623.4	0.47

Values are given as median with interquartile range, or mean ± SD as appropriate.
°C, Centigrade Celsius; IQR, interquartile range; MDI, maximum deflection index; RF, radiofrequency; SD, standard deviation; W, watts
*p<0.05

Table 5. Properties of the fluoroscopy used nine cases according to arrhythmia type and arrhythmia origin

Procedure characteristics (n=9)	**Arrhythmia type**		***p***	**Arrhythmia origin**		***p***
	VT (n=5)	PVC (n=4)		Left sided (n=4)	Right sided (n=5)	
RF lesion, n, mean ± SD (range) 8.7 ± 5.7 (1.0-18.0)	10.2 ± 5.7 (4.0-18.0)	7.0 ± 6.0 (1.0-15.0)	0.4	6.8 ± 5.6 (1.0-14.0)	10.4 ± 5.8 (4.0-18.0)	0.4
Fluoroscopy time, min, mean ± SD (range) 5.2 ± 6.1 (0.2-18.4)	7.9 ± 7.1 (2.6-18.4)	1.8 ± 2.5 (0.2-5.5)	0.1	5.7 ± 8.5 (0.4-18.4)	4.8 ± 4.6 (0.2-12.3)	0.8
Procedure time, min, mean ± SD (range) 181.7 ± 50.6 (110.0-245.0)	190.0 ± 62.4 (120.0-245.0)	177.5 ± 49.7 (110.0-210.0)	0.7	170.0 ± 64.8 (110.0-240.0)	191.0 ± 41.6 (140.0-245.0)	0.6

Values are given as count, mean ± SD and range.
PVC, premature ventricular complex; RF, radiofrequency; SD, standard deviation; VT, ventricular tachycardia

Table 6. Properties of ablations according to being irrigated tip catheter as a first choice

Property	**Irrigated tip catheter as a first choice**		***p***
	Yes (n=22/39)	No (n=17/39)	
RF lesion (n, mean ± SD)	7.5 ± 5.5	12.1 ± 5.5	0.01*
Power			
Average (W, mean ± SD)	25.5 ± 7.5	24.7 ± 9.5	0.8
Maximum (W, median, 25th and 75th IQR)	35.0 (33.7-35.0)	30.0 (30.0-35.0)	0.17
Temperature			
Average (°C, median, 25th and 75th IQR)	32.5 (29.8-35.3)	33.0 (30.5-43.0)	0.3
Maximum (°C, median, 25th and 75th IQR)	32.5 (31.0-39.0)	36.0 (31.5-46.5)	0.16
Energy			
Average (joule, mean ± SD)	929.3 ± 458.7	1018.1 ± 850	0.7
Procedure time (min, mean ± SD)	142.7 ± 40.8	193.9 ± 54.0	0.02*

Values are given as median with interquartile range, or mean ± SD as appropriate.
°C, Centigrade Celsius; IQR, interquartile range; RF, radiofrequency; SD, standard deviation; W, watts
*p<0.05

patients without ablation histories (0.69 ± 0.15% and 0.51 ± 0.12%, respectively, p = 0.002) (Table 4).

No fluoroscopy was used in 30 of the patients, while fluoroscopy was utilized in 9 of the patients. The fluoroscopy times ranged between 0.1 and 3 min in 4 patients and between 3 and 6 min in 3 patients. No significant differences were found between the fluoroscopy times and procedure times among the patients undergoing fluoroscopy in terms of the type and origin of the arrhythmia (Table 5). The ablation was initiated with a 7F, 4 mm standard non-irrigated catheter (Marinr; Medtronic Inc.) in 17 patients, and it was continued with an irrigated tip catheter when the first attempt failed. The procedure time was statistically shorter and less RF was delivered when the irrigated tip catheter was used as the first choice (Table 6). None of the patients developed complications.

During a mean follow-up time of 26.7 ± 13.7 months, the VAs recurred in 9 of the patients (23%). Five of the patients who developed recurrences had RVOT VT and 4 had RVOT PVCs. Repeat ablations were performed successfully in 4 of the patients who developed recurrences. Three of the patients who developed recurrences were followed-up with sotalol, flecainide, and propranolol without problems. The remaining two patients with recurrences underwent the ablation procedure again. Despite the fact that right-sided ablations were previously performed successfully in these two patients, the ablation could not be carried out in the second procedure because the target point was mapped very close to the coronary artery. These patients were followed up with antiarrhythmic medications.

Discussion

Although there are studies regarding the use of irrigated catheters in adult catheter ablations and pediatric supraventricular tachycardia catheter ablations, there are insufficient studies regarding the use of irrigated catheters with 3DMS guidance in pediatric VA ablations.[7-12] This study indicated that irrigated catheters can be used with high success and reliability rates in VA catheter ablations in pediatric patients.

In school screening programs, the VA incidence in children was 0.2–0.8/10,000, which is less than that in adult patients.[13-14] As seen in the present study, most pediatric VAs have RVOT origins, and they can be successfully treated with catheter ablations at a rate of 60–90%.[14-17]

In our study, the VAs were successfully ablated from the left ventricular outflow tract (LVOT) in 3 patients. In the evaluation of 2 of the patients who previously underwent successful RVOT VA ablations, the target point was close to the coronary artery in the second study. However, the number of such cases will increase with the advancements and experience in mapping technology. The coronary artery proximity should be well-assessed when a VA ablation is performed from the LVOT in order to avoid catastrophic coronary complications. In our clinic, we begin mapping from the RVOT in terms of procedure safety in all pediatric patients. No complications were seen in any of the patients in our study.

The procedures were performed in all of the patients with the guidance of 3DMS using limited/ zero fluoroscopy. Limited fluoroscopy was used in 9 of the 39 patients. Overall, the radiation dose is proportional to the lifelong cancer risk, and this association is important for both pediatric patients with long-life expectancy and laboratory personnel.[18-19] In addition to decreasing the use of fluoroscopy, 3DMS also increases the success of the procedure. The important advantages of this system include the clear definition of the anatomical structures and the ability to re-access to the same anatomical point when desired.

All of our patients who developed recurrences had RVOT originating VAs. However, no recurrences were found in any of the patients with LVOT originating VAs who underwent successful ablations. This may be because of the better catheter stability in the aortic cusps and the easier retroaortic catheter manipulation when compared to the RVOT.

The RF energy could not be delivered in 2 of the patients who previously underwent successful ablations and developed recurrences during the follow-up because the ablation target was close to the coronary artery. In such cases, it is a safe approach to postpone the operation until the patient grows. The pediatric patient group has a long-life expectancy, experience with coronary interventions in this population is low, and effective medication alternatives are available.

Deeper lesions are created with irrigated catheters when compared to non-irrigated catheters, making them more effective in epi-

cardial localized arrhythmia foci. In addition, the formation of coagulum and thrombi is lower.[20] In our study, there were higher MDI values in the 8 patients who previously underwent failed VA ablations than in the patients who underwent ablations for the first time in our clinic, which is consistent with this situation. An irrigated catheter was used as the first choice in more than 50% (22/39, 56%) of our patients. Moreover, the number of RF lesions and procedure time, which are the risk factors for complications, were less in this group than in the other patient group. An irrigated catheter can be chosen as the first option in RFAs of pediatric VAs. However, future randomized controlled studies will reach more definitive results. The literature states that the risk of steam pops increases when the RF power rises above 30 W; however, no audible steam pops were observed in our study.[20]

In our study group, before the ablation, mild left ventricular dysfunction was found in 3 patients and dilated cardiomyopathy was found in one patient; however, the cardiac functions improved in these patients after the ablation. Tachycardia mediated cardiomyopathy (TMC) has been more commonly defined in supraventricular arrhythmias and in idiopathic ventricular outflow tract tachycardia.[21-24] The improved cardiac functions in our 4 patients after their ablations indicated that the current conditions were TMCs, and successful ablation treatments are important in children with long life expectancies.

A successful PVC ablation was performed in one 14-year-old patient followed-up with the diagnosis of long QT because of PVCs that triggered an ICD storm. Although there are similar cases in the literature, no pediatric case has been reported thus far.[25-26]

Alcohol ablation, coil embolization, simultaneous unipolar or bipolar RF ablation, surgical ablation, and noninvasive ablation with stereotactic radiosurgery can be performed in adults in order to increase the VA ablation success rate; however, it is obvious that further studies and experience are needed in order to apply these methods in pediatric patients.[6] In one study evaluating epicardial ablations in pediatric patients, with 50% of 10 procedures being VA ablations in 9 pediatric patients, it was reported that epicardial ablations can be carried out in resistant VAs.[27] However, further studies are needed in order to use epicardial ablations, which are being increasingly performed in adult patient groups, in pediatric VA patients.

The limitations of this study include its single center and retrospective design, as well as the limited number of patients because VAs are seen infrequently in children. The relatively short follow-up duration was another limitation. Finally, the lack of a control group without the use of 3DMS was another limiting factor.

Conclusions

Irrigated catheters can be used with high success and low complication rates in VA ablations with the guidance of 3DMS in pediatric patients. The use of fluoroscopy can be significantly limited in irrigated VA ablations using 3DMS, and successful ablations can be performed in most cases with zero fluoroscopy.

Conflict of Interests

None

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