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ORIGINAL ARTICLE

Transitioning from Radiofrequency Ablation to Cryoablation for Treatment of Pediatric Atrioventricular Nodal Reentrant Tachycardia: A Single Tertiary Center Experience

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Abstract

Catheter ablation of the slow pathway is the recommended treatment for atrioventricular nodal reentrant tachycardia (AVNRT) in children. Both radiofrequency ablation (RF) and cryoablation (CA) have been used for this purpose. In this report, we describe our experience during the transition period from RF to CA for the treatment of pediatric AVNRT. Between January 2012 and August 2021, a retrospective evaluation was conducted of the clinical features, procedural outcomes, and follow-ups of pediatric AVNRT patients who underwent catheter ablation at a pediatric electrophysiology center. The catheter ablation outcomes of 89 pediatric AVNRT patients were evaluated: 29 patients were ablated using RF (RF group) and 60 patients were ablated using CA (CA group). No significant difference was found between the groups in terms of gender, age, weight, and success and recurrence rates. The procedure duration and total lesion numbers were statistically significantly lower in the RF group compared with the CA group (86.67 ± 45.8 and 156.1 ± 37.7 min; $p = 0.01$, 4 [3–6] and $p < 0.01$, 8 [7–9] lesions, respectively). Catheter ablation was successful in all patients. There were no permanent complete atrioventricular blocks in both groups. A total of six patients (6.8%) developed recurrences. The cryoablation of pediatric AVNRT is a safe and effective procedure with comparable acute and mid-term follow-up success rates compared with RF, even during a period of transition from RF to CA.

Keywords Children · Radiofrequency ablation · Cryoablation · Atrioventricular nodal reentrant tachycardia

Introduction

Catheter ablation of the slow pathway is the recommended treatment for atrioventricular nodal reentrant tachycardia (AVNRT) in children, as it is in adults. Both radiofrequency ablation (RF) and cryoablation (CA) have been used for this purpose [1–3]. A non-trivial risk of adverse consequences, such as complete heart block for RF, and a tendency for higher recurrence rates in CA have been previously reported [4, 5]. Despite late recurrences being more commonly associated with CA compared with RF, the avoidance of permanent atrioventricular block makes CA a safer and more attractive option for the treatment of pediatric AVNRT [6, 7]. Comparable results for complete heart block and recurrence rates for CA and RF are also reported in adults [7, 8]. Since November 2016, when it first became available for our department, we have exclusively used CA for all AVNRT ablations in our pediatric electrophysiology clinic. In this report, we describe our experience during the transition period from RF to CA for the treatment of pediatric AVNRT.

Material and Methods

Study Population

Between January 2012 and August 2021, a total of 89 children and adolescents (< 18 years of age) underwent catheter ablation for AVNRT at our center. We evaluated the catheter ablation outcomes, patients' characteristics, and patient follow-ups. The hospital records of 89 pediatric patients were examined by dividing the patients into two groups based

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on the received catheter ablation procedure: radiofrequency ablation (RF) or cryoablation (CA). Data regarding the patients' clinical characteristics, electrocardiographic and Holter findings, echocardiographic examinations, ablation procedures, and follow-up were obtained from the hospital records. This study was approved by the local scientific committee, and it complied with the Declaration of Helsinki.

Electrophysiological Study and Ablation

Written-informed consent was obtained from the patients' parents, and antiarrhythmic medications were withdrawn at least five half-lives prior to the electrophysiological study (EPS). The EPS was performed under general anesthesia in 54 patients and under conscious sedation with propofol, ketamine, and midazolam in the remaining 35 patients. The ablation indications of the patients were inducible AVNRT and dual-node physiology with documented tachycardia. In our clinic, EnSite NavX /Precison (Abbott/St. Jude Medical Inc., St. Paul, MN, USA) is used as three-dimensional electroanatomic system (EMS) in pediatric catheter ablations. If EMS was activated, fluoroscopy may not be used in some of the procedures.

Radiofrequency Ablation

Patients underwent EPS and ablation in the electrophysiology lab using conventional catheter mapping (Schwarzer Cardiotek Engineering, Heilbronn Germany) using an EP tracer (Version V90) for the mapping. The RF catheters, multicurve/bidirectional monocurve ablation catheters with 4-mm tips (Marinr RF; Medtronic, MN; Livewire, Abbott Medical Inc., MN), were chosen according to the operator's preference.

The radiofrequency energy was delivered by a temperature-controlled generator, with a maximum power of 50 W and a maximum temperature of 60 °C. Ablation started at 30 W and was up-titrated to 50 W until the appearance of a nodal ectopic beat, indicating the modification of an atrioventricular node. Slow pathway anatomic ablation was performed while monitoring for the presence of accelerated junctional rhythm. Fast pathway conduction was retrogradely monitored during junctional rhythm. Energy application was terminated if ventriculoatrial dissociation was seen or the junctional rate was > 150 beats/min.

Cryoablation

Cryoablation was performed using either a 6- or 8-mm-tip Freezor catheter with a CryoConsole (CryoCath Technologies Inc.). Ablation was performed during free-running AVNRT or normal sinus rhythm depending on the inducibility of the tachycardia. In patients with non-inducible AVNRT, ablation was carried out during sinus rhythm. First, an atrioventricular signal ratio of approximately 1:2 with or without slow pathway potentials was determined. A linear ablation was then undertaken between the tricuspid valve annulus, in the lower portion of the middle third of the triangle of Koch, and the orifice of the coronary sinus. If there was residual evidence of a slow pathway, a second linear ablation was performed with more caudal progression toward the compact AV node. The application was aborted if PR lengthening or a second-degree AV block was seen.

During tachycardia, cryoenergy was delivered in the area of the slow pathway, which was typically found in the mid-to-lower third of the triangle of Koch. Success was achieved when AVNRT was terminated. If no effect was seen after 20 s at < 0 °C of cryolesion, the application was aborted, and an attempt was made in another area. If AVNRT was terminated by slowing during the first 20 s, cryotherapy was continued for up to 240 s. After the first lesion to stop the tachycardia, ablation was continued as for a normal sinus rhythm.

After a 30-min waiting period, tachycardia inducibility was controlled with atrial/ventricular pacing in association with intravenous metaproterenol sulfate/isoproterenol. The absence of inducible AVNRT and/or double echo beats were accepted as endpoints. After the procedure, continuous telemetry monitoring by a 12-lead electrocardiogram and echocardiography were performed during a 1-day stay in the hospital for all patients. The patients were discharged 24 h after the procedure in a stable condition. They were asked about their symptoms during the first and subsequent every sixth-month follow-ups and evaluated by ECG, with echocardiography in selected patients, and Holter monitoring at each follow-up.

Statistical Analysis

Statistical analyses were performed using SPSS 15 software (SPSS, Inc., IL). The data distribution pattern was evaluated using the Kolmogorov–Smirnov test. Data were expressed as the mean ± standard deviation or median, with an interquartile range. The categorical variables were statistically compared across the groups using the χ^2 test or when the expected value in a cell was < 5, the Fisher exact test. Comparisons of continuous variables between the two groups were performed using an unpaired Student's t test or a Mann–Whitney U test. Values of $p < 0.05$ were considered statistically significant.

Results

The catheter ablation outcomes of 89 pediatric AVNRT patients were evaluated: 29 patients were ablated using RF (RF group) and 60 patients were ablated using CA (CA group). The patients' basic characteristics are shown in Table 1. No significant difference was found between the groups in terms of gender, age, and weight, while significant differences were found between them with regard to the follow-up duration. Seventy of the patients did not receive any drugs before the procedure, while 19 received at least one antiarrhythmic drug. When evaluating the accompanying cardiac comorbidities, one patient had moderate mitral insufficiency, one patient had a small ventricular septal defect, and one patient in the RF group had a small atrial septal defect. Within the CA group, one patient had a high venosus atrial septal defect, two patients had bicuspid aortic valves, and three patients had patent foramen ovalia. For both groups, the most common reason for ablation was family choice. One patient in the RF group and three patients in the CA group had undergone previous RF attempts at other centers. According to the baseline ECGs of the patients who underwent ablation, documented tachycardia was found in 83 (93.2%) of the patients. The remaining six patients complained about palpitation. For one patient, cardioversion had been used for acute tachycardia management in an emergency clinic in another center. For the management of acute tachycardia, 68 patients received adenosine and 14 patients received intravenous antiarrhythmic medication. The procedural data are shown in Tables 2 and 3 and Fig. 1. In the CA group, 9F 8-mm-tip cryocatheters were used successfully in 31 patients and 7F 6-mm-tip cryocatheters were used successfully in 29 patients. In addition, a 7F 4-mm-tip RF catheter was used in all but one of the RF ablations. In the RF group, a 5F 4-mm-tip RF catheter was used for only one patient.

The procedure duration and total lesion numbers were statistically significantly lower in the RF group compared with the CA group (86.67 ± 45.8 and 156.1 ± 37.7 min; $p = 0.01$, 4 [3–6] and $p < 0.01$, 8 [7–9] lesions, respectively).

Catheter ablation was successful in all patients. No complications were seen in 83 patients, three patients developed right bundle branch blocks, and three patients developed a subcutaneous hematoma at the vascular access site. A total of six patients developed temporary right bundle branch blocks. In the CA group, two patients developed temporary complete atrioventricular blocks. All temporary events were resolved during the procedure. There were no complete atrioventricular blocks in the RF group.

Table 1 Characteristics of the patients

Characteristics	All ($n = 89$)	RF group ($n = 29$)	CA group ($n = 60$)	p value
Age at intervention, years (median,25th and 75th IQR)	14 (12.5–16)	14 (13–16)	14 (12.2–16)	0.5
Sex (M/F)	33/56	15/14	18/42	0.05
Weight, kg (average ± SD)	52.7 ± 13.9	53.3 ± 13.9	52.4 ± 13.9	0.7
Symptoms, n				
Palpitation	6	0	6	
Documented tachycardia	83	29	54	
Acute Management				
Antiarrhythmic *	14	8	6	
Adenosine	68	20	48	
Cardioversion	1	1	0	
Prior Medication				
None	70	22	48	
1 drug	16	5	11	
2 drugs	3	2	1	
Cardiac comorbidity	9	3 **	6 ***	

Values are given as count (%) or average ± SD as appropriate

CA cryoablation, *RF* radiofrequency ablation, *M* male, *F* female, *SD* standard deviation

*Beta blocker, amiodarone, calcium channel blocker

**1 patient with moderate mitral insufficiency, 1 patient with small ventricular septal defect, 1 patient with small atrial septal defect

***1 patient with high venosus atrial septal defect, 2 patient with bicuspid aortic valve, 3 patient with patent foramen ovale

Table 2 Procedural data of the procedures

Characteristics	All ($n=89$)	RF group ($n=29$)	CA group ($n=60$)	p value
Procedure time, min (average ± SD)	134.5 ± 51.5	86.67 ± 45.8	156.1 ± 37.7	*0.001*
TCL	296.5 ± 47.9	289.7 ± 46.5	299.2 ± 48.7	0.4
Total lesion number, *n* (median, 25th and 75th IQR)	8 (5–9)	4 (3–6)	8 (7–9)	*< 0.001*
Acute ablation success, *n* (%)	89	29	60	NS

Values are given as count (%), median with interquartile range, or average ± SD as appropriate

CA cryoablation, *RF* radiofrequency ablation, *SD* standard deviation, *TCL* tachycardia cycle length, *IQR* interquartile range

Table 3 Complications of ablation procedures and follow up

	All ($n=89$)	RF group ($n=29$)	CA group ($n=60$)
Temporary events*			
None	81 (%90.1)	27 (% 93.1)	54 (% 90)
Transient RBB	6 (% 6.8)	2 (% 6.9)	4 (% 6.7)
Transient Complete AV Block	2 (% 2.3)	0	2 (% 3.3)
Complication, *n* (%)			
No	83 (% 93.3)	27 (% 93.1)	56 (% 93.3)
Vascular complication	3 (% 3.4)	1 (% 3.4)	2 (% 3.4)
Complete RBB	3 (% 3.4)	1 (% 3.4)	2 (% 3.4)
Recurrence rate, *n* (%)	6 (% 6.8)	2 (% 6.8)**	4 (% 6.7)***
Follow up duration, months (median,25th and 75th IQR)	32 (19–42.5)	60 (19–90)	27.5 (19.2–37.5)

Values are given as count (%), median with interquartile range, or average ± SD as appropriate

CA cryoablation, *RF* radiofrequency ablation, *SD* standard deviation, *IQR* interquartile range, *RBBB* right bundle branch block, *AV* atrioventricular

*Completely resolved in a few seconds to minutes before the end of the procedure

**One patient underwent cryoablation and one patient underwent RF ablation

***All patients underwent succesful cryoablation

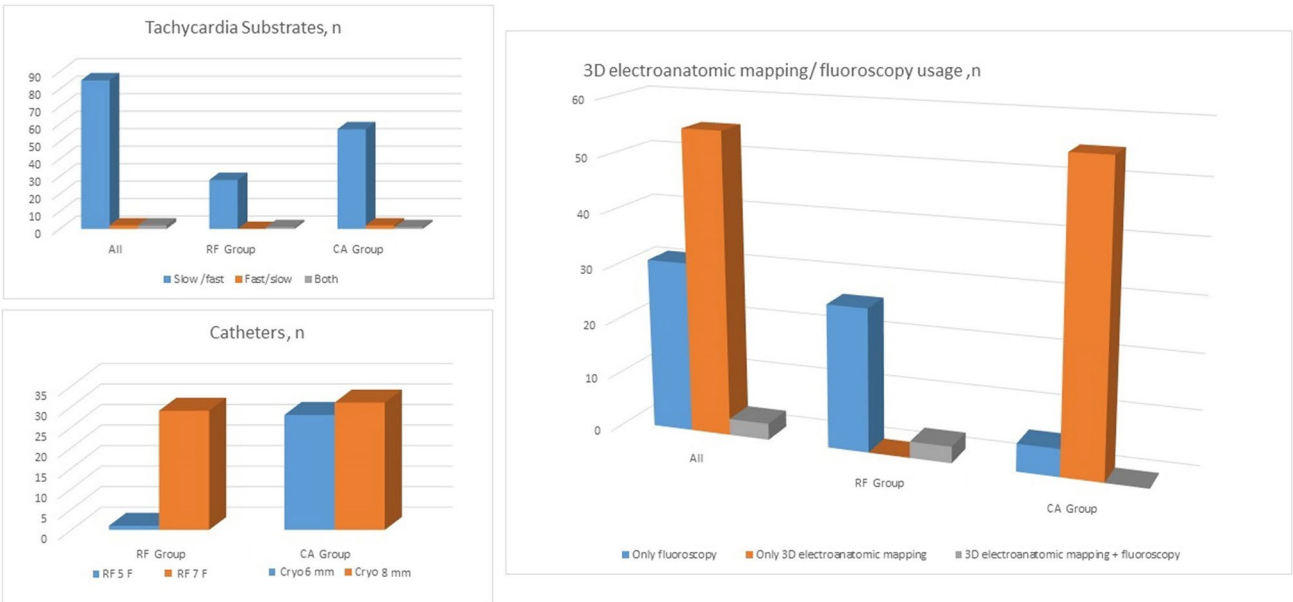

Fig. 1 Additional procedural data (tachycardia substrates of the patient's, catheter and fluoroscopy/electroanatomic mapping usage)

Four patients in the CA group required extra lesion applications during the waiting period (two patients in the 8-mm-tip group and two patients in the 6-mm-tip group). However, no patient in the RF group required extra lesion applications during the waiting period.

Cryoablation

A total of 60 children (42 females and 18 males) underwent CA for AVNRT. Comparing the two catheter-tip subgroups, age and weight were significantly lower in the 6-mm-tip group than in the 8-mm-tip group (11.8 ± 3.1 and 14.9 ± 1.56 years; $p = 0.001$, 44.29 ± 11.7; $p = 0.001$, 59.48 ± 11.8, respectively). Additionally, the number of cryoablation applications was statistically higher for the 8-mm-tip group compared with the 6-mm-tip group (8 [6–8] vs. 9 [8–10], $p = 0.02$). No significant difference was found between the catheter-tip subgroups in the CA group in terms of the total lesion duration, procedure duration, recurrence rate, and follow-up duration (Table 4).

Follow-Up

The follow-up duration was statistically significantly lower in the CA group than in the RF group (27.5 [19.2–37.5] months and 60 [19–90] months, respectively; $p < 0.001$) because this was a comparison study between our previous (RF) and current methods (CA). A total of six patients (6.8%) developed recurrences. Successful cryoablations were performed in the second sessions of five of these patients, and RF was repeated in one of these patients.

Discussion

In our population, the acute success and early-to-mid-term recurrence rates of CA were not statistically different from those of RF. Despite the learning curve associated with the introduction of a new method, CA had similar outcomes to RF. In contrast to previous studies, our data show early procedural success and median-term follow-up success comparable to RF when using CA for pediatric AVNRT [9, 10]. The safety and efficacy of RF for pediatric AVNRT were also demonstrated in this study. However, the gap between our experience with RF and CA must be considered: in our institution, CA is the newer method for pediatric AVNRT ablation.

RF of AVNRT has proven to be an effective therapy in the pediatric population. However, children are considered to be particularly vulnerable to atrioventricular block complications due to their smaller heart and triangle of Koch. The possible benefits of CA compared with RF include a lower risk of catheter dislodgment during ablation due to cryoadherence to the tissue, reversible effect, and the creation of more homogeneous and well-demarcated lesions [11, 12]. The comprehensive consequence is that the theoretical safety advantage favors CA.

The total lesion number was higher in the CA group than in the RF group, which led to procedural times being longer in the CA group. Creating an effective lesion can take up to 4 min on average when using CA compared with an average of 1 min for RF; however, we believe that the time required for CA will reduce as performing physicians become more familiar with CA. Further studies are needed on the adequate numbers of cryolesions and the effects of extra cryolesions on pediatric AVNRT ablation.

A retrospective cohort study of 96 AVNRT ablation cases for children reported that the average total costs for CA and RF were similar [13]. We think that in our country, CA seems more costly than RF; however, no

Table 4 Comparison of patient characteristics and procedural data in terms of cryoenergy catheter tip (6-mm vs. 8-mm)

Characteristics	All ($n = 60$)	6-mm-tip ($n = 29$)	8-mm-tip ($n = 31$)	p value
Age, years (average ± SD)	13.4 ± 2.8	11.8 ± 3.1	14.9 ± 1.56	*0.001*
Weight, kg (average ± SD)	52.4 ± 13.9	44.29 ± 11.7	59.48 ± 11.8	*0.001*
Sex (M/F)	18/42	8/21	10/21	0.7
Total lesion number, *n* (median,25th and 75th IQR)	8 (7–9)	8 (6–8)	9 (8–10)	*0.02*
Total lesion duration, sec (average ± SD)	1901.9 ± 591.4	1732.5 ± 555.8	2064.1 ± 589.9	0.06
Procedure time, min (average ± SD)	156 ± 37.7	153.2 ± 42	158.7 ± 33.5	0.5
Recurrence rate, *n* (%)	4 (% 6.7)	2 (% 6.9)	2 (% 6.5)	0.9
Follow up duration, months (average ± SD)	26.1 ± 12.6	29.13 ± 10.9	23.4 ± 13.7	0.08

Values are given as count (%), median with interquartile range, or average ± SD as appropriate

SD standard deviation, *IQR* interquartile range

country-specific studies have been undertaken on this topic. The increased cost for cryocatheters is certainly an issue, especially at centers that resterilize RF catheters, such as our institution. However, a potential saving associated with CA is that it is possible to perform cryoablation with a success rate similar to RF, especially during the learning period without major complications.

A subanalysis of the CA group showed that there was no difference between 6- and 8-mm-tip cryocatheters in terms of success and recurrence rates. First experience with cryoablation in pediatric AVNRT patients was obtained with a 4-mm-tip catheter [14]. Das et al., according to a multicenter study, reported that recurrence after cryoablation was more common after using 4-mm-tip cryocatheters than 6- to 8-mm-tip cryocatheters [15]. This might be explained by smaller catheter tips creating smaller lesions. There is limited data available for the acute and long-term effects of using 8-mm-tip catheters for pediatric AVNRT cryoablation. An experimental study demonstrated that an 8-mm-tip cryocatheter led to larger lesion sizes than 4- and 6-mm-tip catheters, so this catheter-tip size was thought to be more effective for slow pathway ablation in pediatric AVNRT [16]. However, possible limitations of 8-mm-tip catheters are their stiffness, which may lead to inadvertent transient atrioventricular block; their large thickness, which requires a large sheat, and the large tip size. In the same study [15], a higher recurrence rate was reported for 8-mm-tip cryocatheters than for 6-mm-tip cryocatheters (15.4% and 4.5%; $p = 0.018$, respectively). This result was attributed to lower operator experience with 8-mm-tip catheters compared with 6-mm-tip catheters. In contrast, our study demonstrated similar results and recurrence rates for both 6-mm-tip and 8-mm-tip catheters.

Limitations

The small number of patients included in our study limited the statistical analysis. Other limitations may have included it being a single-center study and the relatively short duration of the follow-up. It has been reported that a significant portion of recurrences after both CA and RF occur > 5 years post ablation [17]. The follow-up duration in our cohort was nearly five years for the RF group but not as long for the CA group.

Conclusion

The cryoablation of pediatric AVNRT is a safe and effective procedure with comparable acute and mid-term follow-up success rates compared with RF, even during a period of transition from RF to CA.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent Informed consent was obtained from the children's parents/guardians.

Research Involving with Human and Animal Participants This article does not contain any studies with animals performed by any of the authors.

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