Pediatr Cardiol (2017) 38:1220–1225
DOI 10.1007/s00246-017-1648-z

ORIGINAL ARTICLE

Comparison of 6-mm Versus 8-mm-Tip Cryoablation Catheter for the Treatment of Atrioventricular Nodal Reentrant Tachycardia in Children: A Prospective Study

Volkan Tuzcu[1] · Enes Elvin Gul[1] · Mehmet Karacan[1] · Hacer Kamali[1] · Nida Celik[1] · Celal Akdeniz[1]

Received: 23 October 2016 / Accepted: 2 June 2017 / Published online: 13 June 2017

Abstract Due to its safety profile, cryoablation (Cryo) for atrioventricular nodal reentrant tachycardia (AVNRT) is more commonly preferred over radiofrequency (RF) ablation in children in recent years. Recent studies demonstrated high long-term success rates comparable to radiofrequency ablation. The aim of this prospective study was to compare the efficacy and safety of an 8-mm-tip versus 6-mm-tip Cryo catheter in the treatment of AVNRT in children. A total of 125 consecutive patients over 10 years of age with AVNRT were included. EnSite system (St. JudeMedical, St Paul, MN, USA) was used to reduce or eliminate fluoroscopy. The acute procedural success was 100% in both groups. The prodecure duration for the 8-mm-tip group was shorter (151.6 ± 63.2 vs. 126.6 ± 36.7 min, $p < 0.01$, respectively). Fluoroscopy was used in only 7 patients. The mean follow-up duration was 14.6 ± 8.4 months (median 13.5 months, min. 3 months and max. 27 months). The recurrence rate for AVNRT was also comparable between the two groups (6-mm tip: 9.6 vs. 8-mm tip: 8%). Cryo of AVNRT is a safe and effective procedure with comparable acute and mid-term follow-up success rates using 6-mm and 8-mm-tip catheters in children. In addition, procedure duration is shorter with an 8-mm-tip Cryo catheter.

Keywords Cryoablation · AVNRT · Catheter tip · Recurrence

✉ Enes Elvin Gul
elvin_salamov@yahoo.com

[1] Pediatric and Genetic Arrhythmia Center, Istanbul Medipol University, TEM Avrupa Otoyolu Goztepe Cikisi, No 1, Bagcilar, 14, Istanbul, Turkey

Introduction

Atrioventricular nodal reentrant tachycardia (AVNRT) is one of the most common supraventricular tachycardia (SVT) substrates targeted for catheter ablation in children. In recent years, cryoablation (Cryo) for AVNRT is more commonly preferred over radiofrequency (RF) ablation in children due to its safety. RF ablation for AVNRT carries a 1–3% risk of permanent atrioventricular block (AVB) [1]. Besides, RF ablation can cause pain, thromboembolic events, cardiac perforation, and coronary artery injury [2]. However, Cryo has a less risk of thromboembolic events, and there is no report of permanent AVB. Additionally, Cryo is a painless procedure which increases patient comfort, reduces the operator stress [3].

First reports of Cryo in pediatric patients showed higher recurrence rates than RF ablation [4, 5]. However, recent studies which assessed Cryo in AVNRT demonstrated high long-term success comparable to RF ablation [6–10]. However, there is limited data regarding the comparison of 6-mm and 8-mm Cryo catheters [11]. The aim of this prospective study was to compare the efficacy and safety of 8-mm-tip versus 6-mm-tip Cryo catheter for the treatment of AVNRT in children.

Materials and Methods

A total of 125 consecutive patients over 10 years of age with AVNRT were included. Since a 10 Fr sheath is needed for the 8-mm-tip catheter, patients less than 10 years-of-age were not included. During this prospective study, 6-mm and 8-mm-tip catheters were selected in a consecutive manner so that every other catheter selection would be the same to reach equal number in both groups. EnSite

system (St. Jude Medical, St Paul, MN, USA) was used to reduce or eliminate fluoroscopy.

Patients with AVNRT who underwent Cryo during the inclusion period of July 2012 to November 2014 were included in the study. The local ethics committee approved the study protocol and informed written consent was obtained from all patients. A 12-lead electrocardiogram (ECG) and 24-hour ambulatory Holter monitoring were performed in all patients. Furthermore, all anti-arrhythmic drugs were discontinued for at least five half-life periods prior to the procedure.

Electrophysiology Study

A standard EPS was performed. AVNRT was diagnosed if inducible during an EPS or, if not inducible, on the basis of a documented narrow complex tachycardia with a short VA interval (<70 ms) in a typical form of AVNRT (slow–fast) and long VA interval (VA > 70 ms) in atypical AVNRT (fast–slow or slow–slow), [1] after the demonstration of an AH jump, which is defined by a sudden prolongation of the AH interval by ≥50 ms when shortening the cycle length of atrial pacing, or the coupling interval of the atrial extrastimulus by 10 ms and echo beats clearly diagnostic of dual-AV nodal physiology, and [2] after AV accessory pathway and other possible atrial tachycardias were ruled out with EP maneuvers like entrainment (Morady maneuver), His-refractory premature ventricular delivery, and parahisian pacing. All procedures were performed under deep sedation. If AVNRT was not inducible at baseline, intravenous orciprenaline was administered. Cryo was performed using a 7 Fr cryoablation catheter (Medtronic Inc, Minneapolis, MN) with a 6-mm-tip electrode or a 9 Fr catheter with an 8-mm-tip electrode.

EnSite navigation system (St. Jude Medical, St. Paul, MN) was used in all patients, and the majority of the procedures were performed without fluoroscopy (Fig. 1). If a 6-mm-tip catheter was used, cryomapping was carried out by a progressive reduction of temperature to −30 °C, for a maximum duration of 60 s. When an 8-mm-tip catheter was used, test lesions were delivered for up to 30 s. Cryomapping or test lesions were applied in the anatomical slow pathway region where a local slow pathway electrogram was present with an A to V amplitude ratio of around 1:4 to 1:2. If AVNRT was inducible, cryomapping or test lesions were initiated during AVNRT, and successful termination of the AVNRT with block in the slow pathway was accepted as a sign of success. During instances of inducible AVNRT, or echo beats, cryomapping or test lesions were initiated at the slow pathway location using programmed electrical stimulation and lack of inducible echo beats or nonsustained runs of AVNRT were sought as an end point. If single echo beats persisted in some cases, no further lesions were delivered. If AVNRT was still inducible during initial application, mapping was stopped and the catheter was subsequently placed at a different site for another cryomapping lesion. Initial successful Cryo lesions were delivered for 6 min. Additional lesions lasting for 4 min were placed at the successful site towards the septum or coronary sinus ostium in order to form an ablation line. If AVNRT was still inducible during Cryo or an instance of transient AV block occurred, cryoenergy was stopped and further test lesions were applied at other potential target sites. The efficacy of the procedure was

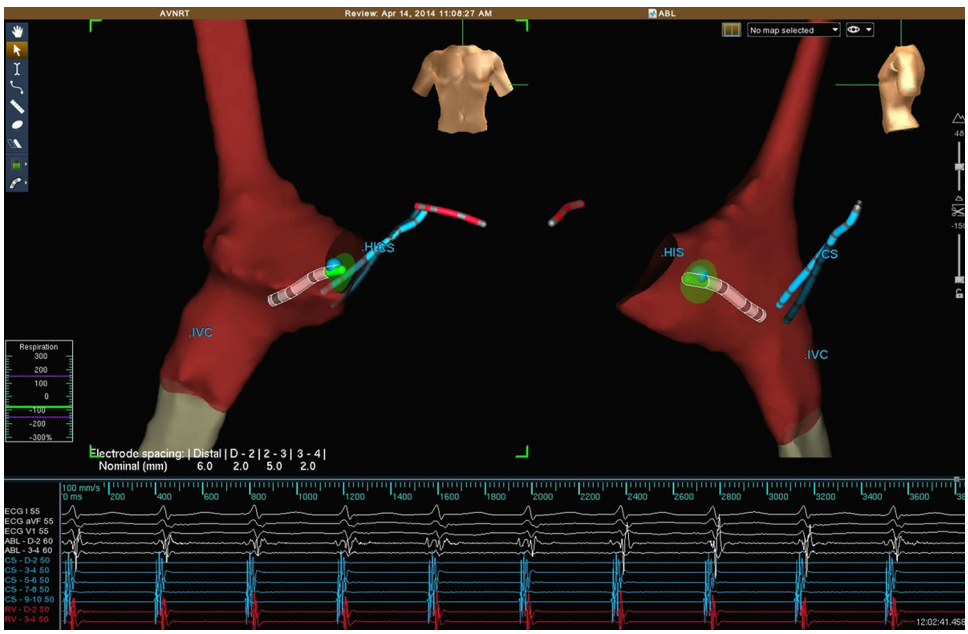

Fig. 1 Electroanatomical right atrial geometry showing catheters including coronary sinus catheter (*blue tube*) and right ventricular catheter (*red tube*) as well as cryoablation catheter (*green tube*). (AP view on the *left*, LL view on the *right*)

assessed in terms of disappearance of dual-AV node physiology and/or lack of inducibility of AVNRT. After a successful ablation, a waiting period of 30 min was initiated and a repeat electrophysiological stimulation was performed at the end, both on and off orciprenaline infusion. If the endpoints were achieved, the procedure was terminated and catheters were subsequently removed. After the procedure, the patients were continuously monitored in hospital for at least 24 h to screen for AV block or any potential complications. Lastly, patients were discharged on no anti-arrhythmic medications.

Outcome

The primary outcome for this study was acute success of Cryo, which is defined as achieving the endpoints of the procedure. Routine follow-up was scheduled at 10 days, 3 months, 6 months following ablation in the outpatient clinic, and as necessary thereafter. Furthermore, recurrence was defined as documented SVT on 12-lead ECG, 24-hour ambulatory monitoring, or event monitoring.

Statistical Analysis

Data were analyzed using SPSS software version 15.0 (SPSS, Chicago, IL, USA) and presented as mean ± standard deviation. The distribution of the variables was analyzed with the Kolmogorov–Smirnow test. Differences between two groups were tested using independent Student's t-tests for normally distributed variables, and the Mann–Whitney *U* test for non-parametrically distributed variables. Differences between the categorical variables were analyzed using the χ^2-test. Stepwise multivariate logistic regression was used to determine the predictors of recurrence. *P* value of less than 0.05 was considered statistically significant.

Results

Patient Characteristics

A total of 125 children; 65 females and 60 males, underwent Cryo for AVNRT. The mean age and weight were 14.3 ± 2.1 years and 57.4 ± 20.4 kg, respectively. Congenital heart disease (CHD) was present in 12% (15 patients) of the patients. Nine patients had atrial septal defect, two had ventricular septal defect, two presented with pulmonary stenosis, one had corrected-TGA, and lastly, one patient had bicuspid aortic valve. Patient demographics and clinical features are presented in Table 1.

Table 1 Demographic and clinical characteristics of the patients

Age, years	14.3 ± 2.1
Weight, kg	57.4 ± 20.4
Female, *n* (%)	65 (52)
CHD, *n* (%)	15 (12)
Additional arrhythmia substrate, *n* (%)	16 (13)
Types of AVNRT, *n* (%)	
Typical	114 (91)
Atypical	8 (6.5)
Both	3 (2.5)

CHD Congenital heart disease, *AVNRT* atrioventricular nodal reentrant tachycardia

Procedural Characteristics

Typical AVNRT was diagnosed in 114 patients, fast–slow type atypical AVNRT in 8 patients, and both types were present in 3 patients. Sixteen patients had additional arrhythmia substrates (8 accessory pathways, 5 ventricular tachycardia, 3 focal atrial tachycardia). The mean procedure time was 138.2 ± 52.1 min. Fluoroscopy was used in only seven patients and the mean fluoroscopy time was 2.7 ± 2.6 min in these procedures. The overall acute success rate was 100% in both groups. Comparing the two catheter groups, procedure duration was significantly shorter in the 8-mm tip group than in the 6-mm tip group (126.6 ± 36.7 vs. 151.6 ± 63.2, $p < 0.01$, respectively). Additionally, the number of RF applications was higher for the 6-mm tip group compared to the 8-mm tip group (8.5 ± 3.0 vs. 7.7 ± 1.8, $p = 0.07$); however, this did not reach statistical significance. There were 8 procedures, which required extra lesion applications during the 30-minute waiting period (3 patients in the 8-mm tip group, and 5 patients in the 6-mm tip group).

Sub-analysis of patients with CHD ($n = 15$) showed that procedure duration was longer than patients without CHD (169 vs. 138 min, $p < 0.01$).

Complications

A total of 29 patients (23%) developed variable degrees of transient AV block during their procedure. All of these blocks completely resolved in a few seconds to minutes before the end of the procedure. To further point out, there was no significant difference between the 6-mm and 8-mm Cryo in terms of transient AV block (21 vs. 25%, $p = 0.67$, respectively). No permanent AV block was observed in either group and no major complications occurred. Both fluoroscopy times and number of complete lesions were comparable between the groups (Table 2). Lastly, fluoroscopy was not used in 118 patients.

Table 2 Comparison of patient characteristics and procedural data in terms of catheter tip (6-mm vs. 8-mm)

	6-mm-tip ($n = 62$)	8-mm-tip ($n = 63$)	p-value
Age, years	14.3 ± 1.9	14.4 ± 2.3	0.96
Weight, kg	54.2 ± 16.5	60.6 ± 23.1	0.07
Procedure duration, min	151.6 ± 63.2	126.6 ± 36.7	<0.01
Number of lesions, mean	8.5 ± 3.0	7.7 ± 1.8	0.07
Follow-up duration, months	15.6 ± 8.3	13.5 ± 8.2	0.17
Recurrence rate	6/62 (9.6%)	5/63 (8%)	0.81

Follow-up

No patients were lost to follow-up. The mean and median follow-up times were 14.5 ± 8.2 months and 13.5 months (minimum: 3 months, maximum: 27 months), respectively. Time to recurrence of AVNRT varied from 33 days to 12.5 months with a median recurrence time of 5.1 months. The recurrence time was not significantly different between the two groups ($p = 0.56$). To determine the predictors for AVNRT recurrence, we performed a logistic regression analysis using multiple variables including age, weight, cryoablation lesions, and catheter tip size. Neither catheter tip nor the Cryo lesion number were predictors of recurrence (Table 3). Among 122 patients who had acute procedural success, 11 had documented recurrence of AVNRT (9%). Of the 11 patients with recurrence following Cryo, five underwent successful repeat ablation (one patient with RF and four patients with 8-mm Cryo).

Discussion

This is a prospective study, which compares 6-mm and 8-mm Cryo catheter use in children with AVNRT. Our findings demonstrate that Cryo with an 8-mm-tip catheter is as safe and effective as the 6-mm-tip catheter with comparable recurrence rates. The only significant difference was in the procedure duration. In addition, the number of lesions was higher in the 6-mm-tip catheter group with a trend towards statistical significance ($p = 0.07$). Catheter tip size did not predict recurrence following AVNRT ablation and no permanent AV block was observed during the follow-up period. Sub-analysis of patients with CHD showed that procedure duration was significantly longer than in patients without CHD. This difference may be explained with altered anatomy and substrate in patients with CHD.

Table 3 Results of logistic regression analysis considering age, weight, lesion count, and catheter tip (6-mm) in relation to the long-term recurrence

	OR	95% CI	p value
Age	1.05	0.77–1.42	0.77
Weight	1.01	0.99–1.04	0.24
Number of lesions	0.90	0.67–1.21	0.49
Catheter tip (6 mm)	1.21	0.34–4.34	0.77

Initial experience with Cryo use in pediatric AVNRT patients was obtained with a 4-mm-tip catheter [5]. A higher recurrence rate has been reported with a range between 7 and 20% with the 4-mm-tip catheter [3]. However, a lower recurrence rate (6–10%) was reported with larger catheter tips. A multicenter experience of Cryo for AVNRT in children demonstrated a higher success and lower recurrence rate with a 6-mm-tip catheter when compared to the 4-mm-tip catheter [11]. The 4- and 6-mm-tip catheters create smaller lesion sizes than the 8-mm-tip catheter, which might explain the findings. There is limited information available regarding acute and long-term effects of an 8-mm-tip catheter. Experimental studies have demonstrated that the 8-mm-tip Cryo catheter leads to a significantly larger lesion size than the smaller tip catheters, and thus, this electrode was thought to be more effective and attractive for slow pathway elimination [12]. Nevertheless, there are a number of possible limitations of an 8-mm-tip catheter, including stiffness, difficulty in safe manipulation, and large tip size which may lead to less ideal catheter positioning during lesions, and the risk of inadvertent transient AV block. Silver and colleagues [13] performed the first retrospective review of pediatric patients with AVNRT treated with an 8-mm-tip Cryo at three large pediatric arrhythmia centers, and found that Cryo with an 8-mm-tip ablation catheter is both safe and effective with a low risk of recurrence (2.8%), and has a higher acute procedural success (91%) than Cryo performed with a 6-mm-tip Cryo catheter. In the multicenter retrospective study by Das and colleagues [11], a higher recurrence rate was reported with 8-mm-tip Cryo catheter when compared to 6-mm-tip Cryo catheter (15.4 and 4.5%, $p = 0.018$, respectively). They explained this finding with a learning curve for operators who were not experienced with the 8-mm-tip catheter. In contrast with this study, the current study demonstrated comparable results between 6-mm-tip and 8-mm-tip catheters. The recurrence rates were also comparable. The only significant difference was in procedure duration, which was shorter in the 8-mm-tip

Cryo group. This finding may partially be explained with the lack of cryomapping feature in the 8-mm-tip Cryo catheter. Although the number of Cryo lesions was higher in the 6-mm-tip catheter group, this difference did not reach statistical significance ($p = 0.07$). The 8-mm-tip Cryo catheter was used for treating AVNRT in the adult population, and it achieved comparable acute procedural success and low recurrence rates (5.6%) to RF ablation [8]. A recent prospective study investigating Cryo with an 8-mm-tip catheter found a low recurrence rate (4.9%) with no observed permanent AV block. [14]. Very recently, meta-analysis including 5617 patients in 14 trials showed that Cryo is a safe and effective treatment for AVNRT [10].

Follow-up period is also important in terms of recurrence. Most recurrences occur 1–2 years after Cryo, indicating the importance of a longer follow-up [15]. In our study, the mean follow-up time was 15 months (minimum: 3 months, maximum: 27 months). In addition, the long-term success rate following Cryo can improve with increasing operator experience [16]. There are potential new methods to improve acute and chronic success rate of Cryo: (a) lengthier Cryo procedure time (approximately 7 min per cryoablation) and additional Cryo lesions [17], (b) larger Cryo catheter tip, (c) application of lesions with double freezing cycles (freeze–thaw-freeze) [18], and (d) linear ablation lesions [19].

In regard to transient AV block during the procedure, the use of an 8-mm-tip catheter leads to a higher rate of transient AV block ranging from 11 to 15% when compared to the 6-mm-tip catheter [8, 14]. The absence of a cryomapping mode and larger size lesions with the 8-mm-tip catheter may explain this finding. In our study, the rate of transient AVB was found as 23% and there were no difference between the 6-mm and 8-mm catheter tip groups.

An important feature of this study is the non-fluoroscopic approach, which was achieved in most cases (118 out of 125 patients). There are few studies showing significant reduction in fluoroscopy for pediatric patients with SVT [20–23]. In our study, only seven patients were exposed to radiation because of complex CHD.

Study Limitations

There are number of limitations that need to be mentioned. This is a single center, prospective study; therefore, larger randomized studies are needed to support our findings. A longer follow-up period could allow for precision in recurrence rates. In addition, the learning curve with 8-mm-tip catheter may also influence our results.

Conclusions

Cryo of AVNRT is a safe and effective procedure with comparable acute and mid-term follow-up success rates using both 6-mm 8-mm-tip catheters in children.

Compliance with Ethical Standards

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

References

1. Van Hare GF, Javitz H, Carmelli D, Saul JP, Tanel RE, Fischbach PS, Kantel RJ et al (2004) Prospective assessment after pediatric cardiac ablation: demographics, medical profiles, and initial outcomes. J Cardiovasc Electrophysiol 15(7):759–770
2. Hindricks G (1993) The Multicentre European Radiofrequency Survey (MERFS): complications of radiofrequency catheter ablation of arrhythmias. The Multicentre European Radiofrequency Survey (MERFS) investigators of the Working Group on Arrhythmias of the European Society of Cardiology. Eur Heart J 14(12):1644–1653
3. de Sisti A, Tonet J (2012) Cryoablation of atrioventricular nodal reentrant tachycardia: a clinical review. Pacing Clin Electrophysiol 35(2):233–240
4. Deisenhofer I, Zrenner B, Yin YH, Pitschner HF, Kuniss M, Grossmann G, Stiller S et al (2010) Cryoablation versus radiofrequency energy for the ablation of atrioventricular nodal reentrant tachycardia (the CYRANO Study): results from a large multicenter prospective randomized trial. Circulation 122(22):2239–2245
5. Collins KK, Dubin AM, Chiesa NA, Avasarala K, Van Hare GF (2006) Cryoablation versus radiofrequency ablation for treatment of pediatric atrioventricular nodal reentrant tachycardia: initial experience with 4-mm cryocatheter. Heart Rhythm 3(5):564–570
6. Chan NY, Mok NS, Lau CL, Lo YK, Choy CC, Lau ST, Choi YC (2009) Treatment of atrioventricular nodal re-entrant tachycardia by cryoablation with a 6 mm-tip catheter vs. radiofrequency ablation. Europace 11(8):1065–1070
7. Chan NY, Choy CC, Lau CL, Lo YK, Chu PS, Yuen HC et al (2011) Cryoablation versus radiofrequency ablation for atrioventricular nodal reentrant tachycardia: patient pain perception and operator stress. Pacing Clin Electrophysiol 34(1):2–7
8. Chan NY, Mok NS, Choy CC, Lau CL, Chu PS, Yuen HC, Lau ST (2012) Treatment of atrioventricular nodal re-entrant tachycardia by cryoablation with an 8-mm-tip catheter versus radiofrequency ablation. J Interv Card Electrophysiol 34(3):295–301
9. Kimman GP, Theuns DA, Szili-Torok T, Scholten MF, Res JC, Jordaens LJ (2004) CRAVT: a prospective, randomized study comparing transvenous cryothermal and radiofrequency ablation in atrioventricular nodal re-entrant tachycardia. Eur Heart J 25(24):2232–2237
10. Hanninen M, Yeung-Lai-Wah N, Massel D, Gula LJ, Skanes AC, Yee R, Klein GJ et al (2013) Cryoablation versus RF ablation for AVNRT: A meta-analysis and systematic review. J Cardiovasc Electrophysiol 24:1354–1360
11. Das S, Law IH, Von Bergen NH, Bradley DJ, Dick M 2nd, Etheridge SP, Saarel EV et al (2012) Cryoablation therapy for atrioventricular nodal reentrant tachycardia in children: a multicenter experience of efficacy. Pediatr Cardiol 33(7):1147–1153

12. Khairy P, Rivard L, Guerra PG, Tanguay JF, Mawad W, Roy D, Talajic M et al (2008) Morphometric ablation lesion characteristics comparing 4, 6, and 8 mm electrode-tip cryocatheters. J Cardiovasc Electrophysiol 19(11):1203–1207
13. Silver ES, Silva JN, Ceresnak SR, Chiesa NA, Rhee EK, Dubin AM, Avasarala K et al (2010) Cryoablation with an 8-mm tip catheter for pediatric atrioventricular nodal reentrant tachycardia is safe and efficacious with a low incidence of recurrence. Pacing Clin Electrophysiol 33(6):681–686
14. Peyrol M, Sbragia P, Uhry S, Boccara G, Dolla E, Quatre A, Guenoun M et al (2013) Slow pathway elimination for atrioventricular nodal reentrant tachycardia with the 8-mm tip cryoablation catheter: an 18-month follow-up study. J Interv Card Electrophysiol 37(1):105–109
15. LaPage MJ, Saul JP, Reed JH (2010) Long-term outcomes for cryoablation of pediatric patients with atrioventricular nodal reentrant tachycardia. Am J Cardiol 105(8):1118–1121
16. Cokkinakis C, Avramidis D, Alexopoulos C, Kirvassilis G, Papagiannis J (2013) Cryoablation of AVNRT in children and adolescents: improved long-term outcomes with increasing experience. Hellenic J Cardiol 54:186–191
17. Drago F, Silvetti MS, De Santis A, Grutter G, Andrew P (2006) Lengthier cryoablation and a bonus cryoapplication is associated with improved efficacy for cryothermal catheter ablation of supraventricular tachycardias in children. J Interv Card Electrophysiol 16(3):191–198
18. Schneider HE, Stahl M, Kriebel T, Schillinger W, Schill M, Jakobi J, Paul T (2012) Double Cryoenergy Application (Freeze-Thaw-Freeze) at Growing Myocardium: lesion volume and effects on coronary arteries early after energy application. Implications for efficacy and safety in pediatric patients. J Cardiovasc Electrophysiol 24:701–707
19. Czosek RJ, Anderson J, Marino BS, Connor C, Knilans TK (2010) Linear lesion cryoablation for the treatment of atrioventricular nodal re-entry tachycardia in pediatrics and young adults. Pacing Clin Electrophysiol 33:1304–1311
20. Tuzcu V (2012) Significant reduction of fluoroscopy in pediatric catheter ablation procedures: long-term experience from a single center. Pacing Clin Electrophysiol 35:1067–1073
21. Smith G, Clark JM (2007) Elimination of fluoroscopy use in a pediatric electrophysiology laboratory using three-dimensional mapping. Pacing Clin Electrophysiol 30:510–518
22. Scaglione M, Ebrille E, Caponi D, Blandino A, DI Donna P, Siboldi A, Bertero G et al (2013) Single center experience of fluoroless AVNRT ablation guided by Electroanatomical Reconstruction in children and adolescents. Pacing Clin Electrophysiol 36:1460–1467
23. Casella M, Dello Russo A, Pelargonio G, Del Greco M, Zingarini G, Piacenti M et al (2016) Near zerO fluoroscopic exPosure during catheter ablAtion of supRavenTricular arrhYthmias: the NO-PARTY multicentre randomized trial. Europace 18:1565–1572