Journal of Interventional Cardiac Electrophysiology (2019) 55:99–104
https://doi.org/10.1007/s10840-018-0499-8

Catheter ablation for supraventricular tachycardia in children ≤ 20 kg using an electroanatomical system

Serhat Koca [1,2] · Celal Akdeniz [1] · Volkan Tuzcu [1]

Received: 20 September 2018 / Accepted: 17 December 2018 / Published online: 3 January 2019

Abstract

Purpose Catheter ablation is the only choice of treatment in some small children with medically refractory supraventricular tachycardia (SVT). Electroanatomical mapping systems (EMS) are more commonly utilized in electrophysiological procedures in recent years, which resulted in a significant decrease in fluoroscopy exposure. The potential benefit of EMS in small children has not been studied. Therefore, we investigated the outcomes of children undergoing catheter ablation weighing ≤ 20 kg using an electroanatomical mapping system.

Methods This study evaluated the outcomes, characteristics, and follow-ups of children ≤ 20 kg who underwent SVT ablations between April 2012 and April 2018 in a pediatric electrophysiology center where EMS were routinely used.

Results In a 6-year period, 1129 children underwent SVT catheter ablation under EMS guidance at our institution. A total of 84 of them were weighing ≤ 20 kg. The acute success rate was 97.6% in 85 tachycardia substrates. No fluoroscopy was used in 58 of the patients, while a median of 5 (4–14) min of fluoroscopy was used in the remaining 26 patients. Recurrences were seen in 4 patients (4.8%) at a mean follow-up of 3.89 ± 2.08 years. Five patients developed non-vital complications (2 right bundle block and 3 temporary complete block that spontaneously resolved during the procedure).

Conclusions The outcome of catheter ablation with the guidance of EMS for the treatment of SVT in small children is favorable. Fluoroscopy exposure can be decreased and even eliminated in most patients.

Keywords Small children · Catheter ablation · Electroanatomical mapping systems · Supraventricular tachycardia · Fluoroscopy exposure

1 Introduction

Nowadays, catheter ablation has become the standard therapy for supraventricular tachycardia (SVT) in adults and school-aged children, as well as in selected small children [1–4]. However, in children under 20 kg, when considering their anatomically smaller and more immature cardiac structure and vessels, a catheter ablation for the treatment of SVT becomes the first-line option when the tachycardia is resistant and cannot be controlled medically. Moreover, also in infants, catheter ablation can be used for curative therapy, if tachycardia cannot be safely controlled despite medical therapy [4, 5]. It has been shown that fluoroscopy, which is used in catheter ablations, can be significantly reduced by using electroanatomical mapping systems (EMS) in children who are more susceptible to the dangerous effects of high levels of radiation, since they are in a rapid somatic growth and cellular maturation period [6–11]. In this report, we aimed to evaluate the outcomes of children weighing ≤ 20 kg undergoing SVT ablation at our center where EMS is routinely used, focusing on feasibility and complications.

2 Material and methods

2.1 Study population

In our clinic, an EMS (EnSite NavX system; Abbott/St. Jude Medical Inc., St. Paul, MN, USA) is routinely used in pediatric catheter ablations, and fluoroscopy is not used in most of these ablation procedures. A total of 1129 children underwent SVT ablation under EMS guidance at our institution between

✉ Serhat Koca

[1] Pediatric and Genetic Arrhythmia Center, Pediatric Cardiology, Istanbul Medipol University, Istanbul, Turkey

[2] Pediatric Cardiology, Yuksek Ihtisas Hospital, Ankara, Turkey

April 2012 and April 2018. The catheter ablation outcomes, patients' characteristics, and follow-ups in children ≤ 20 kg were evaluated. In this study, the records of 84 pediatric patients were examined by dividing the patients into two groups based on their weights (≤ 15 kg and 16–20 kg) referring to prior literature [1]. This study was approved by the local scientific committee, and it complied with the Declaration of Helsinki.

2.2 Electrophysiological study and ablation

Written informed consent was obtained from the patients' parents, and the antiarrhythmic medications were withdrawn at least 5 half-lives prior to the electrophysiological study (EPS). The EPS was performed under general anesthesia in seven patients and under conscious sedation with propofol, ketamine, and midazolam in the remaining 77 patients. The ablation indications of the patients were uncontrolled/recurrent tachycardia episodes despite antiarrhythmic medication and tachycardia-induced cardiomyopathy.

First, after placing the surface electrodes, skin patches were applied to anesthetized/sedated patient to guide the non-fluoroscopic navigation system (EnSite NavX). In the standard procedure, one deflectable quadripolar 5F/7F catheter was inserted into the right atrium without fluoroscopy via the right femoral vein in all cases. An additional one or two 4F/5F sheaths were inserted into the left femoral vein. Mapping and ablation were performed with/without fluoroscopy using a three-dimensional electrocardiogram (ECG)-based navigation system (EnSite NavX) that allows visualization of all catheters. Appropriate patches for body surface area produced by company for small children were used to acquire electroanatomic maps. In smaller children, hand-trimmed small patches were used. After the EMS activation, the right atrial anatomy was created by using the inserted catheter in the right atrium. After creating the right atrial anatomy, the His and the entrances of the caval veins were marked. Catheters were placed into the right atrium, coronary sinus, and right ventricle with the guidance of the EnSite Velocity system without fluoroscopy in those patients > 10 kg. When a left atrial arrhythmogenic substrate was detected in the patient, we first investigated whether the patient had a patent foramen ovale (PFO). PFO presence was assessed without echocardiography by simply probing the septum in the posterosuperior of the His point at the septal site. In the PFO cases, the left atrium was accessed via the PFO, and an ablation was performed. Fluoroscopy was used for the trans-septal puncture in those patients requiring access to the left atrium. In addition, limited fluoroscopy was used during the EMS-guided diagnostic catheter placement with 3D anatomy creation in children ≤ 10 kg. Atrioventricular nodal reentrant tachycardia (AVNRT) ablations were carried out using only cryoenergy, and the cryocatheters were selected as 7F 6-mm tip (Medtronic, Minneapolis, MN, USA). The radiofrequency (RF) ablation catheters were chosen according to the arrhythmia substrate and the preference of the operator as 5F/7F ablation catheters with 4-mm tips (Mariner RF; Medtronic, Minneapolis, MN, USA) and a 7F irrigated RF ablation catheter with a 4-mm tip (Cool Flex, Abbott/St. Jude Medical Inc., St. Paul, MN, USA). The RF energy was delivered by a temperature-controlled generator. After a successful ablation, there was a 30-min waiting period to assess the recurrence. After the waiting period, adenosine was used to evaluate the success of the AP ablation. Tachycardia inducibility was controlled with atrial/ventricular pacing in association with intravenous metaproterenol sulfate. After the procedure, continuous telemetry monitoring, a 12-lead electrocardiogram, and echocardiography were performed during the 1-day stay of all patients. The patients were discharged 24 h after the procedure. They were asked about their symptoms at the 1st and 6th months, and evaluated with an ECG, and in selected patients with echocardiography, and Holter monitoring at each visit.

2.3 Statistical analysis

Data are expressed as mean ± standard deviation or median with interquartile range. The categorical variables were statistically compared across the groups using the $\chi 2$ 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 Mann-Whitney U test. Values of $p < 0.05$ were considered statistically significant.

3 Results

In this study, the catheter ablation outcomes, patients' characteristics, and follow-ups in children ≤ 20 kg were evaluated. We evaluated a total of 84 patients. Twenty-two of 84 patients were ≤ 15 kg and the remaining 62 weighed between 16 and 20 kg. The patients' basic characteristics are shown in Table 1. Thirty-seven of the patients were not receiving any drugs before the procedure, while forty-seven patients were receiving at least one antiarrhythmic medication. The most common arrhythmia substrate was the AP (23 WPW, 16 concealed accessory pathways, and 3 permanent junctional reciprocating tachycardias). AVNRTs were detected in a total of 30 patients: 5 atypical and 25 typical. A manifest AP ablation and AVNRT ablation were performed on the same patient who was operated on due to a WPW pattern. All of the patients with intra-atrial reentrant tachycardia weighed over 15 kg, while one patient with junctional ectopic tachycardia weighed under 15 kg. When evaluating the accompanying cardiac comorbidities, there were complete atrioventricular septal defects (single ventricle physiology with Glenn palliation) and focal atrial

Table 1 Patients characteristics and tachycardia substrates

Characteristics	All ($n = 84$)	≤ 15 kg ($n = 22$)	> 15 kg ($n = 62$)	p value
Age at ablation, years, (mean ± SD)	4.97 ± 1.67	3.32 ± 1.94	5.54 ± 1.11	*0.001*
Sex (M/F)	33/51	7/15	26/36	0.4
Weight, kg, (median, 25th, and 75th IQR)	18 (16–19)	14 (10–15)	19(17.4–20)	*0.001*
Height,cm, (median, 25th, and 75th IQR)	112 (107–116)	100(75.2–110)	114.5 (110–117.7)	*0.001*
Prior medication				
None	37	1	36	
1 drug	21	7	14	
≥ 2 drugs	26	14	12	
Tachycardia substrates	85*	22	63	
AVNRT	30	2	28*	
WPW	23	7	16*	
Concealed AP	16	6	10	
PJRT	3	3	0	
Focal atrial tachycardia	7	3	4	
IART	5	0	5	
JET	1	1	0	
Cardiac comorbidity	5	2**	3 ***	

AVNRT atrioventricular nodal reentrant tachycardia, *AP* accessory pathway, *F* female, *IART* intra-atrial reentrant tachycardia, *IQR* interquartile range, *JET* junctional ectopic tachycardia, *M* male, *PJRT* permanent junctional reciprocating tachycardia, *SD* standard deviation, *WPW* Wolff Parkinson White. Values are given as count (%), median with interquartile range, or mean ± SD as appropriate. $p < 0.05$ is significant

[*] One patient underwent WPW and AVNRT ablation at same procedure

[**] 1 patient with unbalanced complete atrioventricular septal defect who underwent Glenn operation, 1 patient tachycardiomyopathy due to focal atrial tachycardia

[***] 1 patient with operated atrial septal defect, 1 patient with dilated cardiomyopathy, 1 patient with operated atrial and ventricular septal defects

tachycardia-related tachycardiomyopathy in two patients who weighed ≤ 15 kg. In the > 15 kg group, two patients underwent operations for congenital heart diseases (one due to an atrial septal defect, and one due to atrial and ventricular septal defects), while an additional patient had dilated cardiomyopathy.

The procedural data are shown in Tables 2 and 3. No significant difference was found between either group in terms of the procedure time, fluoroscopy time, and acute success rate. Eight of the 19 left atrium-originated tachycardia substrate ablations were performed via the foramen ovale, while the remaining 11 were performed via a transseptal puncture. Twelve of 22 patients in ≤ 15-kg group and 46 of 62 patients in > 15-kg group underwent catheter ablation completely non-fluoroscopic. In our study, cryoenergy was used in 54, RF energy in 27, and both energy sources in 3 patients. Cryoenergy was used in the ablations of all AVNRTs and the right septal region-originated substrates,

Table 2 Procedural data of ablation procedures and follow-up duration

Characteristics	All ($n = 84$)	≤ 15 kg ($n = 22$)	> 15 kg ($n = 62$)	p value
Procedure time, min, (median, 25th, and 75th IQR)	144 (120–180)	150 (110–195)	137.5 (120–161)	0.6
Fluoroscopy time, min, (median, 25th, and 75th IQR)	5 (4–14) (n = 26 patients)	6.7 (4.9–13.25) (n = 10 patients)	4.4 (1.7–18.75) (n = 16 patients)	0.2
WCL, ms, (average ± SD)	287.7 ± 57.4	262.9 ± 41.3	295.6 ± 59.8	*0.04*
SVT CL, ms, (median, 25th, and 75th IQR)	280 (260–300)	300 (260–320)	270 (250–300)	0.25
Acute success, n (%)	82/84 (97.6%)	21/22	61/62	0.4
Recurrence rate, n (%)	4/84 (4.8%)	4	0	*0.004*
Follow-up duration, years, (average ± SD)	3.89 ± 2.08	4.8 ± 2.37	3.56 ± 1.89	*0.02*

IQR interquartile range, *SD* standard deviation, *SVT CL* supraventricular tachycardia cycle length, *WCL* Wenchebach point. Values are given as count (%), median with interquartile range, or mean ± SD as appropriate. $p < 0.05$ is significant

Table 3 Additional procedural data and complications ablation procedures

Characteristics	All ($n = 84$)	≤ 15 kg ($n = 22$)	> 15 kg ($n = 62$)
Ablation lesion number, *n*, (median, 25th, and 75th IQR)			
Cryo	7 (5–9)	6 (4–7)	7 (5–9)
RF	3 (2–4)	3 (2–5)	2 (2–4)
Left atrial access, *n*			
Via foramen ovale	8	5	3
Via trans-septal puncture	11	1	10
Ablation energy, *n*			
Radiofrequency	27	8	19
Cryoablation	54	12	42
Both	3	2	1
Catheter			
4-mm 5F RF	5	5	0
4-mm 7F RF	24	5	19
Irrigated RF	1	0	1
6-mm Cryo	57	14	43
Complication, *n*			
No	79	22	57
Right bundle brunch block	2	0	2*
Temporary complete block in the procedure	3	0	3**

* 1 patient with temporary and 1 patient with permanent right bundle brunch block

** Completely resolved in a few minutes during the procedure

IQR interquartile range, *RF* radiofrequency. Values are given as count (*n*) or median with interquartile range as appropriate

and RF energy was used in all the left side-originated substrates. In addition, cryoenergy was used in all but one of the right free wall-originated AP ablations. The most commonly used energy was cryoablation and only a 6-mm type cryoablation catheter. The follow-up duration was statistically significantly lower in the ≤ 15-kg group than in the > 15-kg group (4.8 ± 2.37 years and 3.56 ± 1.89 years, respectively, $p = 0.02$). No complications were seen in 79 patients; 2 patients developed right bundle branch blocks and 3 patients developed temporary complete atrioventricular blocks that were resolved in the procedure. A total of four patients (4.8%) developed recurrences. All of the recurrences occurred in the ≤ 15-kg group (one patient with WPW, two with concealed AP, and one with PJRT). In the two patients with recurrences, cryoenergy was used, and in the other two patients, radiofrequency energy (4-mm 5F non-irrigated tip) was used. Successful ablations were performed in the second sessions in two patients with recurrences. Of the other two patients, one is being followed up with sotalol and the other with flecainide and propranolol therapies without problems.

4 Discussion

Since the introduction of transcatheter ablation in the 1990s, there has been significant technical development and ablation has now become the standard therapy in older children and adults [12]. Although a catheter ablation is the first line of therapy for the treatment of SVT in adults and older children, medical therapy is preferred in smaller children due to their small, immature cardiac and vascular structures, and due to the potential spontaneous resolution of atrial and AP-related tachycardias over time [13]. Previously, some case series, especially regarding RF ablations in infants and small children, were published with a success rate between 74% and 93% [3, 4, 14, 15]. A body weight ≤ 15 kg was demonstrated as an independent risk factor for complications during the catheter ablation [1, 16].

In our study, no complications were seen in the ≤ 15-kg group. Moreover, the complications observed in the other group were not vital. Trans-septal puncture was performed in 11 patients with a mean age of 5.43 ± 1.07 years old and a mean weight of 18.8 ± 1.1 kg and no complications occurred in that group. Trans-septal puncture is an interventional procedure that has been used for a long time with proven efficacy and reliability in adults [17, 18]. Recently, reports have also been published in this issue in children [19, 20]. For example, Yoshida et al. reported pericardial effusion in only one patient among 43 pediatrics patients with a mean weight of 21 kg, while Ehrlinspiel et al. reported no complications in 157 children with a median weight of 42 kg. However, an evaluation of the reliability of a trans-septal puncture, especially in small children, with larger patient groups will provide more accurate knowledge. In our routine practice, first, the presence of a PFO was evaluated when a left atrial originated arrhythmia was identified. In these cases with PFO, a trans-septal puncture was not performed. This approach shortens the fluoroscopy and procedure times, and it can completely eliminate the fluoroscopy requirement in some cases.

Another point of concern in catheter ablations in small children is the potentially long fluoroscopy time during the procedures. This is an important issue for the patient as well as for the laboratory personnel [21–23]. Advances in technology seen in the last two decades have led to the development of EMS to guide ablation and to reduce fluoroscopy during prolonged catheter ablation procedures [24]. In catheter ablations performed in patient groups similar to the present study, the fluoroscopy time was reported as a median of 14.3 min using EMS and a median of 36 min when EMS was not used [25, 26]. In our study, the median fluoroscopy time was 5 min in all of our patients, and no significant difference was found in terms of the fluoroscopy. It should not be considered to replace fluoroscopy with EMS completely. Fluoroscopy should be available to determine the catheter location if there is suspected localization of the catheter within the cardiac chambers. Readily available fluoroscopy is essential to avoid catastrophic complications in catheter ablation. In our study, there was no significant difference between the two groups in the median procedure time, which was 144 min in all of the patients. In a similar patient group, Bachhoff et al. reported a longer median procedure time of 181 min using EMS compared to our study [25].

Significant engineering advances allowed the development of systems for cryoablation in the last three decades [27].

Cryoenergy has been used as an alternative to RF energy and is increasingly being adopted as a first-line energy source in children with AVNRT [28, 29]. While permanent complete AV block was reported using RF energy, no permanent AV block was reported with the cryoenergy use in the literature [30]. In general, cryoenergy is used for the ablation of tachycardia substrates close to His [31]. However, another factor determining the type of energy used is the operator's experience. In our study, cryoenergy was used in the ablations of all AVNRTs and in the majority of the ablation of the right free wall-originated tachycardia substrates (83.4%). Since catheter stability is low in the right free wall, we benefited from the cryocatheter feature of adhesion to the tissue with stable temperatures at the arrhythmia foci. Three patients developed complete blocks that were spontaneously resolved within seconds to a few minutes during the procedure, and one patient developed a right bundle branch block, which was spontaneously resolved during the procedure. A permanent right bundle branch block was observed in only one patient. All of the transient blocks occurred during the use of the cryocatheter. Cryocatheters are stiffer than diagnostic electrophysiology catheters and non-irrigated RF catheters, and the maneuverability of cryocatheters is lower. For these reasons, it was believed that the mechanical properties of the cryocatheters were effective in the development of these complications. In addition, increased effect of radiofrequency lesion with age had shown previously in an animal study of newborn lambs [32]. Mechanical properties of the cryocatheters and increased effect of radiofrequency lesion with age should be considered in catheter ablation of small children. We speculate that with the advancements and gained experience in ablation, imaging, and mapping system technologies, better results and lower complication rates can be achieved in catheter ablations in small children.

In the patients with recurrences, cryoenergy (6-mm tip cryocatheter) was used in two patients and RF energy (4-mm 5F non-irrigated tip) was used in the other two patients. No recurrences were seen in the patients in whom the 7F RF catheters were used, which may have been due to a larger lesion size at the arrhythmia focus with this catheter. In addition, all of the patients who developed recurrences were in the < 15-kg group, which may be partially explained by the statistically longer follow-up duration in this group when compared to the other group.

5 Conclusion

Catheter ablation is feasible in small children with the use of EMS and the results in terms of success rate, complications, and recurrence rate are acceptable. In small children, fluoroscopy use in catheter ablation can be significantly decreased and be even eliminated in most. However, EMS cannot completely replace with fluoroscopy and fluoroscopy should be easily available in every pediatric electrophysiology procedure.

Compliance with ethical standards

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.

References

1. Kugler JD, Danford DA, Houston KA, Felix G. Pediatric radiofrequency catheter ablation registry success, fluoroscopy time, and complication rate for supraventricular tachycardia: comparison of early and recent eras. J Cardiovasc Electrophysiol. 2002;13:336–41.
2. Van Hare GF, Javitz H, Carmelli D, Saul JP, Tanel RE, Fischbach PS, et al. Prospective assessment after pediatric cardiac ablation: demographics, medical profiles, and initial outcomes. J Cardiovasc Electrophysiol. 2004;15:759–70.
3. Aiyagari R, Saarel EV, Etheridge SP, Bradley DJ, Dick M 2nd, Fischbach PS. Radiofrequency ablation for supraventricular tachycardia in children < or =15 kg is safe and effective. Pediatr Cardiol. 2005;26:622–6.
4. Chiu SN, Lu CW, Chang CW, Chang CC, Lin MT, Lin JL, et al. Radiofrequency catheter ablation of supraventricular tachycardia in infants and toddlers. Circ J. 2009;73:1717–21.
5. Akdeniz C, Ergul Y, Kiplapinar N, Tuzcu V. Catheter ablation of drug resistant supraventricular tachycardia in neonates and infants. Cardiol J. 2013;20:241–6.
6. Gerber TC, Carr JJ, Arai AE, Dixon RL, Ferrari VA, Gomes AS, et al. Ionizing radiation in cardiac imaging: a science advisory from the American Heart Association Committee on Cardiac Imaging of the Council on Clinical Cardiology and Committee on Cardiovascular Imaging and Intervention of the Council on Cardiovascular Radiology and Intervention. Circulation. 2009;119:1056–65.
7. Miyake CY, Mah DY, Atallah J, Oikle HP, Melgar ML, Alexander ME, et al. Nonfluoroscopic imaging systems reduce radiation exposure in children undergoing ablation of supraventricular tachycardia. Heart Rhythm. 2011;8:519–25.

8. Ozyilmaz I, Ergul Y, Akdeniz C, Ozturk E, Tanidir IC, Tuzcu V. Catheter ablation of idiopathic ventricular tachycardia in children using the EnSite NavX system with/without fluoroscopy. Cardiol Young. 2014;24:886–92.
9. Smith G, Clark JM. Elimination of fluoroscopy use in a pediatric electrophysiology laboratory utilizing three-dimensional mapping. Pacing Clin Electrophysiol. 2007;30:510–8.
10. Tuzcu V. Significant reduction of fluoroscopy in pediatric catheter ablation procedures: long-term experience from a single center. Pacing Clin Electrophysiol. 2012;35:1067–73.
11. Drago F, Silvetti MS, Di Pino A, Grutter G, Bevilacqua M, Leibovich S. Exclusion of fluoroscopy during ablation treatment of right accessory pathway in children. J Cardiovasc Electrophysiol. 2002;13:778–82.
12. Asakai H, Kirsh JA. Optimizing outcomes of catheter ablation in infants and toddlers. Expert Rev Cardiovasc Ther. 2015;13:333–40.
13. Brugada J, Blom N, Sarquella-Brugada G, Blomstrom-Lundqvist C, Deanfield J, Janousek J, et al. Pharmacological and non-pharmacological therapy for arrhythmias in the pediatric population: EHRA and AEPC-Arrhythmia Working Group joint consensus statement. Europace. 2013;15:1337–82.
14. Blaufox AD, Paul T, Saul JP. Radiofrequency catheter ablation in small children: relationship of complications to application dose. Pacing Clin Electrophysiol. 2004;27:224–9.
15. Kantoch MJ, Gulamhusein SS, Sanatani S. Short- and long-term outcomes in children undergoing radiofrequency catheter ablation before their second birthday. Can J Cardiol. 2011;27:523.e3–9.
16. Kugler JD, Danford DA, Deal BJ, Gillette PC, Perry JC, Silka MJ, et al. Radiofrequency catheter ablation for tachyarrhythmias in children and adolescents. The Pediatric Electrophysiology Society. N Engl J Med. 1994;330:1481–7.
17. De Ponti R, Zardini M, Storti C, Longobardi M, Salerno-Uriarte JA. Trans-septal catheterization for radiofrequency catheter ablation of cardiac arrhythmias. Eur Heart J. 1998;19:943–50.
18. De Ponti R, Cappato R, Curnis A, Della Bella P, Padeletti L, Raviele A, et al. Trans-septal catheterization in the electrophysiology laboratory: data from a multicenter survey spanning 12 years. J Am Coll Cardiol. 2006;47:1037–42.
19. Yoshida S, Suzuki T, Yoshida Y, Watanabe S, Nakamura K, Sasaki T, et al. Feasibility and safety of transseptal puncture procedures for radiofrequency catheter ablation in small children weighing below 30 kg: single-centre experience. Europace. 2016;18:1581–6.
20. Ehrlinspiel DM, Gass M, Balmer C. Transseptal puncture for radiofrequency catheter ablations of left-sided arrhythmias in a paediatric population. Cardiol Young. 2017;27:267–72.
21. Bashore TM, Bates ER, Berger PB, Clark DA, Cusma JT, Dehmer GJ, et al. Task Force on Clinical Expert Consensus Documents. American College of Cardiology/Society for Cardiac Angiography and Interventions Clinical Expert Consensus Document on cardiac catheterization laboratory standards. A report of the American College of Cardiology Task Force on Clinical Expert Consensus Documents. J Am Coll Cardiol. 2011;37:2170–214.
22. Venneri L, Rossi F, Botto N, Andreassi MG, Salcone N, Emad A, et al. Cancer risk from professional exposure in staff working in cardiac catheterization laboratory: insights from the National Research Council's Biological Effects of Ionizing Radiation VII Report. Am Heart J. 2009;157:118–24.
23. Efstathopoulos EP, Katritsis DG, Kottou S, Kalivas N, Tzanalaridou E, Giazitzoglou E, et al. Patient and staff radiation dosimetry during cardiac electrophysiology studies and catheter ablation procedures: a comprehensive analysis. Europace. 2006;8:443–8.
24. See J, Amora JL, Lee S, Lim P, Teo WS, Tan BY, et al. Non-fluoroscopic navigation systems for radiofrequency catheter ablation for supraventricular tachycardia reduce ionising radiation exposure. Singap Med J. 2016;57:390–5.
25. Backhoff D, Klehs S, Müller MJ, Schneider H, Kriebel T, Paul T, et al. Radiofrequency catheter ablation of accessory atrioventricular pathways in infants and toddlers ≤ 15 kg. Pediatr Cardiol. 2016;37:892–8.
26. An HS, Choi EY, Kwon BS, Kim GB, Bae EJ, Noh CI, et al. Radiofrequency catheter ablation for supraventricular tachycardia: a comparison study of children aged 0-4 and 5-9 years. Pacing Clin Electrophysiol. 2013;36:1488–94.
27. De Ponti R. Cryothermal energy ablation of cardiac arrhythmias 2005: state of the art. Indian Pacing Electrophysiol J. 2005;1:12–24.
28. Papagiannis J, Papadopoulou K, Rammos S, Katritsis D. Cryoablation versus radiofrequency ablation for atrioventricular nodal reentrant tachycardia in children: long-term results. Hell J Cardiol. 2010;51:122–6.
29. Avari JN, Jay KS, Rhee EK. Experience and results during transition from radiofrequency ablation to cryoablation for treatment of pediatric atrioventricula nodal reentrant tachycardia. Pacing Clin Electrophysiol. 2008;31:454–60.
30. Insulander P, Bastani H, Braunschweig F, Drca N, Kennebäck G, Schwieler J, et al. Cryoablation of atrioventricular nodal re-entrant tachycardia: 7-year follow-up in 515 patients-confirmed safety but very late recurrences occur. Europace. 2017;19:1038–42.
31. Andrade JG, Khairy P, Dubuc M. Catheter cryoablation: biology and clinical uses. Circ Arrhythm Electrophysiol. 2013;6:218–27.
32. Saul JP, Hulse JE, Papagiannis J, Van Praagh R, Walsh EP. Late enlargement of radiofrequency lesions in infant lambs: implications for ablation procedures in small children. Circulation. 1994;90:492–9.