Transcatheter Ablation of Supraventricular Tachycardias in Pediatric Patients

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Abstract: Ablation has become an important treatment for many pediatric patients with common supraventricular tachycardias (SVTs). Many multicenter studies have documented that radiofrequency (RF) catheter ablation is a safe and effective procedure for treatment of a large variety of SVTs in children and adults with a high success rate and minimal complications. Novel electrophysiology technologies such as electroanatomic mapping and sophisticated ablating catheters have improved success rates and decreased complications of transcatheter ablation. Moreover, within the last several years, a new energy source using cryoenergy has evolved as a safe and effective alternative for catheter ablation for arrhythmogenic substrates traditionally associated with increased risk when using RF ablation. In this review pediatric transcatheter ablation practice is analysed and discussed with reference to current clinical guidelines.

Key Words: Supraventricular tachycardias; ablation; cryoablation; children.

INTRODUCTION

Ablation has become frontline therapy for many pediatric patients with common supraventricular tachycardias (SVTs). Rather than long-term treatment with medications, ablation offers the possibility of a definitive elimination of SVT substrates. However, the decision to perform transcatheter ablation should be made after full disclosure with the patient and parents about benefits and risk, alternative therapies and the natural history of the SVT.

Radiofrequency (RF) ablation is safe and effective as documented by single- and multi-center pediatric studies. Computer assisted mapping systems used for complex arrhythmias in adult patients have been successfully deployed in selected pediatric patients affected by very complex tachyarrhythmias more often due to a surgical correction of congenital heart disease. Moreover, cryoablation has demonstrated efficacy and safety in locations traditionally associated with increased risk when using RF ablation, particularly around the atrioventricular (AV) node.

RADIOFREQUENCY ABLATION

The use of RF energy has increased greatly during the past 20 years and RF catheter ablation has become a safe and effective procedure for treatment of supraventricular and ventricular arrhythmia in children and adults [1-10]. RF energy is a power source well suited to place focal lesions. A large variety of SVTs can be successfully treated with a high success rate and minimal complications. Technologic advances in energy sources and the development of smaller catheters have made RF energy application the primary method for ablation of tachycardia substrates in pediatric laboratories [11]. As experience with this technique in pediatric patients has grown, efficacy has improved and complications have decreased.

Data from Pediatric Radiofrequency Catheter Ablation Registry of the Pediatric Electrophysiology Society have shown that acute procedural overall success rate of 95,2%, for RF ablation of SVT substrates in children between 1996-1999, could be achieved. In patients with accessory pathways (APs) overall success rate was 94,4% and also the treatment of atrioventricular nodal re-entrant tachycardia (AVNRT) reached an excellent acute and long-term success rate (97-99%). The outcome of patients in the Pediatric Radiofrequency Catheter Ablation Registry showed a reduction of failure rate of 50%, a fluoroscopy time reduction of 20% in 10 years; in addition, the complication rate decreased by 25% [12].

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The safety and efficacy of this technique have been further addressed in multicenter prospective studies designed and implemented as an activity of the Pediatric Electrophysiology Society [13,14]. Therefore, more recent data, obtained by the Registry in patients aged 0 to 16 years with SVT due to APs or AVNRT, showed that the overall success rates for RF ablation is very high (95.7%), with higher success rates for left-sided and particularly left free-wall pathways (97.8%) than right free-wall pathways (90.8%). There were no deaths, and complications of both invasive electrophysiologic studies (EPS) and RF ablation were infrequent (4.2% and 4.0%, respectively).

The risks of RF ablation in children are similar to those in adults and include AV block, bleeding, stroke, infection, damage to cardiac valve, cardiac perforation, coronary spasm and radiation exposure. The most common complication encountered with EPS was hematoma at the catheter entry site. With ablation, the most common complication was AV nodal block (1,2%) and it was limited to ablation of AVNRT (2.1%) and septal pathways (3.0%).

A single-institution study of septal APs ablation in pediatric patients demonstrated an incidence of AV block similar to that reported from the Pediatric Electrophysiology Society [3]. One hundred forty-five procedures were performed in 127 pediatric patients. Permanent second or third degree AV block occurred in 4 (3%) of 136 patients who underwent ablation, involving pathways located near the AV node and His bundle (in the anteroseptal or midseptal position). Recurrence was highest in patients affected by anteroseptal (14%) and midseptal (12%) pathways.

Techniques to avoid inadvertent AV block during effective RF ablation in young patients with septal tachycardia substrates have been investigated by Pecht *et al.* [15]. The techniques included intubation and apnea during RF application, coronary sinus pacing to observe intact AV conduction, power output titration with temperature control, not ablating during tachycardia, and mapping the location of the optimal His-bundle signal prior to RF ablation. A total of 217 consecutive septal tachycardia substrates were included in the study. No transient or permanent complete AV block after any of the 217 substrate ablation procedures was reported and normal AV conduction was seen in all patients during the follow-up. The recurrence rate was 7,9% for patients with AP. This result was comparable to that (12.9%) reported in the Pediatric Radiofrequency Catheter Ablation Registry [16].

In addition to pathway proximity to the normal conduction system, another variable, that could have an effect on the safety and efficacy of RF ablation, is the number of APs present in the patient. At this regard, recently, Weng *et al.* reviewed their institutional experience on the ablation of multiple APs in pediatric patients with

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Wolff-Parkinson-White (WPW) syndrome [17]. Of 317 consecutive patients with WPW syndrome who underwent EPS and RF ablation, 28 (9%) had multiple pathways. Compared with patients with a single pathway, those with multiple pathways had a higher incidence of antidromic tachycardia, a shorter anterograde AP effective refractory period, a longer fluoroscopy time, and a larger number of unsuccessful attempts. However, success rate (92% vs. 93%) and recurrence rate (1.7% vs. 2.1%) were similar in both groups.

Other complications of RF ablation occur much less frequently but have been reported [18-24]. Among them, coronary artery injury, during endocardial ablation on the right and left side of the heart, has been reported [18,21,23].

Patients with congenital heart disease are commonly encountered in the practice of pediatric electrophysiology. The usual anatomic landmarks, used to perform ablations, may be altered or absent. The most recent reports show that in complex congenital heart disease with a surgical biventricular correction, the most common arrhythmia mechanism is a re-entry circuit around an anatomical central obstacle, which in most cases is the tricuspid valve. A linear lesion, connecting electrically silent anatomical structures or areas with extremely reduced voltage or with double potentials, seems to be the best RF ablation strategy [25]. In particular cases, however, the detection of narrow conduction channels between scarred areas, generally located in the right atrial free wall, or the presence of an ectopic focus may allow 'focal' ablation [26]. However, the use the conventional mapping technique could be associated with a low rate of acute success with a high rate of recurrences [27,28]. Recently the use the three-dimensional (3D) mapping system have improved the success rate of these type of ablation procedures. These systems permit to construct anatomical cardiac maps that offer great detail to guide ablation, and also provide voltage information to guide identification of patches and scars.

CARTO™ system (Biosense Webster) uses a magnet mounted under the catheterization table coupled with a proprietary catheter placed in the intracardiac chamber of interest. While the patient is in a stable rhythm, the catheter is manipulated under fluoroscopy while the endocardial surface is mapped. The magnet under the table locates the catheter tip in 3D space when an endocardial signal is measured, and the system stores the spatial and electrical information. The computer then constructs a virtual 3D electroanatomic map of the chamber . The catheter tip location within the mapped space is displayed on the computer screen, allowing catheter manipulation without fluoroscopy.

In pediatric patients, the CARTO™ system has been used to ablate tachycardia substrates in those who have undergone surgical repair of congenital heart disease [25,29-31]. Electroanatomic mapping has been used to delineate conductive tissue within these circuits and the circuit boundaries in order to effectively ablate the tachycardia substrate [32]. In Mustard or Senning baffle affected patients, for example, tissue that is involved in the circuit may be on either side of the baffle, requiring access to both the systemic and pulmonary venous atria to ablate the circuit. Reviewing their experience with combined electroanatomic and entrainment mapping of intra-atrial re-entrant tachycardia (IART) circuits in postoperative Mustard patients, Zrenner *et al.* [31] noted that 10 of 13 circuits involved the tissue between the inferior vena cava–right atrial junction and the tricuspid annulus. Their overall success rate of 86% in ablating these circuits, was facilitated by improved ability to customize the ablation afforded by electroanatomic mapping in conjunction with entrainment mapping of the tachycardia.

Because the CARTO™ system requires multiple sample points to create the endocardial map, obtaining points can be time consuming. Strategies to conserve time and create an accurate endocardial map have been used successfully in the setting of ectopic atrial foci [33].

In addition, nonfluoroscopic 3D navigation systems may significantly reduce x-ray exposure. Drago and co-workers [34] demonstred for the first time in 2002 that ablation of right APs in children could be performed without fluoroscopy using a single catheter with minimal amounts of RF applications. Tuzcu *et al.* [35], very recently, have also documented the safety and efficacy of a nonfluoroscopic approach for EPS and right-sided catheter ablations for SVTs in patients with normal cardiac anatomy using another 3D, surface electrode-based navigation system , the EnSite NavX™ (St. Jude Medical Inc.). This system uses a low energy electrical field created inside the chest by surface electrodes that permits to construct electroanatomic maps.

Non-contact mapping systems (e.g, EnSite, Endocardial Solutions) are also available possible alternative systems. They record far-field potentials and employ solutions to the inverse problem to reconstruct endocardial potentials. Three-dimensional mapping based on a single beat is possible, and the success of ablation in creating conduction block in unique channels can be evaluated [32]. The EnSite system uses a 64-electrode array mounted on a balloon catheter with a 9Fr shaft. The system can be deployed in a cardiac chamber and simultaneous recording of intracavitary electrograms performed. The chamber is delineated with a roving catheter that emits a locator signal. By devising and solving inverse solutions to Laplace's equation, 3.000 virtual electrograms can be calculated. They then are displayed on a computer generated image of the endocardium produced from the information from the locator catheter [11]. An advantage of the EnSite system is that it allows the mapping of focal tachycardias, such as ventricular tachycardia (VT), which may not be hemodynamically tolerated, especially while the patient is under anesthesia, as documented by Paul *et al.* in mapping and ablation of tachycardia originating in the right ventricular outflow tract [36]. However, to actually perform the ablation, the balloon must be partially deflated to allow placement of the ablation catheter. As with many tools and techniques adapted for pediatric use, the size of the equipment relative to the size of the patient is of prime concern and may become a limiting factor. Although this ablation system was demonstrated useful in some pediatric patients, this may not have been as useful in smaller patients for the dimensions of the balloon catheters.

Integration of 3-D electroanatomic mapping with Computed Tomographic (CT) and Magnetic Resonance (MR) imaging is gaining acceptance to facilitate catheter ablation in complex patients. Multislice CT and MR image integration into electroanatomic mapping significantly will improve the success of different arrhythmias substrates. Very few studies has been reported in literature until now [37-40] (see Table **1**).

CRYOABLATION

Within the last several years, a new energy source using cryoenergy has evolved as a safe and effective alternative for catheter ablation for arrhythmogenic substrates in adult patients [41-46]. Recently transcatheter cryoablation delivery systems appropriate for pediatric use have been developed [47-49]. Cryoablation offers several potential advantages compared with RF, with particular regard to safety near the AV node, that makes this energy source particularly attractive for pediatric patients. The ability to cryomap prior to tissue damage provides an added measure of safety and is advanced as the principal feature distinguishing this procedure from the established RF ablation technique. The reversibility of block conduction in particular, *via* a technique known as cryomapping, is an especially useful safety benefit of cryo in clinical practice. Cryomapping allows for the evaluation of the acute effects of cryo on the structures to be ablated before creating a permanent lesion. In addition the formation of an ice ball at the catheter electrode tip permits the adhesion of the catheter tip to the endocardium avoiding dislodgement of the ablation catheter during cryomapping and cryoablation and generating a more specific lesion. Even fluoros-

Table 1. Outcomes of Radiofrequency Treatment of SVTs in Pediatric Patients

Authors, Year	Patients N	Acute Success					Permanent AV Block	Recurrence
		Total%	AVNRT%	AVRT%	EAT%	AFL%		
Mandapati, 2003	127	96%	-	AS AP 96%; MS AP 94%; mouth CS 88%; mCV 100%; R PS AP 100%; L PS AP 96%	-	-	3% (AS and MS AP)	AS AP 14%; MS AP 12%; mouth CS 3%; R PS AP 4%; L PS AP 4%
Van Hare, 2004	481	95,7%	94,6%	L AP 97,8%; R AP 90,8%	-	-	1,2% (2,1% AVNRT, 3% septal AP)	-
Kammeraad, 2004	26	100%	100%	-	-	-	-	11,5%
Collins, 2006	60	100%	100%	-	-	-	-	2%
Lee, 2007	228		97%	92%	82%	91%	-	4,7%

AVNRT = atrioventricular nodal re-entrant tachycardia; AVRT = atrioventricular re-entrant tachycardia; EAT = ectopic atrial tachycardia; AFL = atrial flutter; CS = coronary sinus; mCV = middle cardiac vein; PS AP = posteroseptal accessory pathway; AS AP = anteroseptal accessory pathway; MS AP = midseptal accessory pathway; L = left; R = right.

copy time may significantly be decreased as the cryoadherence allows energy application without fluoroscopy control due to the firm contact of the tip of the catheter to the endocardial surface. Beneficial features include decreased risk of thromboembolism due to little or no endocardial disruption and a lower incidence of coronary artery stenosis after cryoablation in comparison with RF current [50]. Less patient discomfort during cryoenergy application is also reported [51].

The cryomapping (also referred to as ice mapping) is performed by progressive reduction in the tip temperature to -30°C for a maximum time of 60 seconds. This caused, as already said, transient and reversible loss of electrical function at the target site and enabled the acute effects of cryo at a site to be analyzed before the creation of a permanent tissue damage.

When cryomapping is positive (e.g., disappearance or modification of conduction in the target site with no re-induction of tachyarrhythmia or disappearance of ventricular pre-excitation), the tip temperature is decreased further to create a permanent lesion. When cryomapping produces unwanted effects, cryoapplication is stopped to allow tissue rewarming and reversibility of the loss in electrical function.

The cryoablation is performed by cooling the tissue temperature to -75°C. Freezing is maintained at the lowest attainable temperature for a minimum of 4 minutes to a maximum of 8 minutes to create a permanent lesion. During cryoablation, surface electrocardiogram and endocavitary signals must be continuously monitored.

The first study to investigate the potential clinical utility of percutaneous cryoenergy catheter ablation for treatment of SVTs in pediatric patients was conducted by Gaita *et al.* [52] in 2004. Four patients (mean age 14±5 years) affected by permanent junctional reciprocating tachycardia (PJRT) were successfully treated with cryoablation (acute success 100%). The successful site was in the mid-septal region (2 patients), at the coronary sinus orifice (1 patient), and in the middle cardiac vein (1 patient), locations that are associated with higher risk with RF current. No complications were reported. No impairment AV conduction was seen in any patient neither junctional rhythm was observed during either cryomappig or cryoablation. In addition no pain was reported by patients during the procedure, showing another potentially useful feature of cryoablation that may allow significantly less anesthesia use in selected pediatric patients. Only one patient had arrhythmia recurrence 2 months after cryoablation and was treated with a second successful cryoablation procedure. The data reported by these authors suggest that cryoenergy catheter ablation is in this unsual arrhythmia, a safe, effective, and pain-free alternative for treating pediatric patients.

The safety and efficacy of cryoablation were also addressed by Kirsh *et al.* in a multicentric study involved 64 patients (mean age 13±4 years) from 14 participating centers [53]. Thirty patients were affected by AVNRT, 31 patients by AV reciprocating tachycardia (AVRT), 3 patients by VT and two patients by ectopic atrial tachycardia (EAT). Two patients had more than one arrhythmia substrate. Acute success was achieved in 45 of 65 (69%) cryoablation patients. Best success rates were seen in AVNRT (83%) and right septal APs (75%) and lower success rates in other APs (43%), VT (66%) and EAT (0%). No device-related adverts events were reported.

In the same year, the report of Miyazaki *et al.* [54] documented that cryo-therapy could be used to effectively and safely ablate septal tachycardia substrates in pediatric patients. Acute success with cryo-therapy was achieved in 27 (87.1%) of 31 patients (AVNRT 21 of 22, AVRT 5 of 8, VT 1 of 1). The success rate for AVNRT was higher than for AVRT (95.5% vs. 62.5%, $p < 0.05$); however, the recurrence rate was not statistically different. Transient AV block occurred during eight cryoapplications with immediate return of normal AV conduction upon cessation of application. No other complications were reported.

Less satisfactory results were reported by Kriebel *et al.* [55]. Thirty-two patients (mean age 10.1±3.5 years) with SVTs (APs n = 19; AVNRT n = 13) underwent EPS and cryoablation under the guidance of the LocaLisa system. Successful cryoablation was achieved in 24 of 32 patients (75%); in particular, success rate was 68,4% for APs. In the 8 patients in which cryoablation failed, RF current application was effective in 5 resulting in an overall success rate of 90.6%. Cryomapping was predictive for a successful ablation in 83% of the patients while in 4 patients with an AP cryomapping was not predictive for successful cryoablation. This phenomenon may be explained by smaller lesion created at -30°C compared to -75°C. In 6 patients impairment of AV conduction was observed during cryomapping with a rapid return to normal conduction with rewarming. In 3 additional patients with AVNRT transient high-grade AV block occurred during cryoablation despite previous "safe" cryomapping at the same site. In this study the use of cryoenergy for treatment of SVTs in pediatric patients was associated with a lower success rate compared to RF ablation.

Additional reports investigated efficacy and safety of cryoablation in pediatric patients affected by SVTs with the reentry circuit located near the AV junction obtaining an higher success rate than

Table 2. Outcome of Cryoablation Treatment of SVTs in Pediatric Patients

Authors, year	Patients N	Acute Success N (%)						Permanent AV block	Recurrence N (%)
		TOTAL	AVNRT	AVRT	VT	EAT	JET		
Kirsh, 2005	64	45 (69%)	25/30 (83%)	8/11 AS AP (73%) 4/5 MS AP (80%) 6/14 (43% other APs)	2/3 (67%)	0/2* (0%)	-	-	4 (9-14%)
Miyazaki, 2005	31	27 (87,1%)	21/22 (95,5%)	5/8 (62,5%)	1/1 (100%)	-	-	-	3 (11,1%)
Kriebel, 2005	32	24 (75%)	11/13 (84,6%)	13/19 (68,4%)	-	-	-	-	3 (10,3%)
Drago, 2005	26	24 (92%)	13/14 (93%)	11/12 paraHissian (91,5%)	-	-	-	-	7 (29%)
Drago, 2006	36	36 (100%)	19/19 (100%)	15/15 paraHissian (100%)	-	1/1 (100%)	1/1 (100%)	-	3 (10%)
Papez, 2006	81 (83 crio)	73 (88%)	50/53 (94%)	15/20 (85%)	-	4/9 (45%)	1/1 (100%)	-	6 (12,5%)
Collins, 2006	55	54 (98%)	54/55 (98%)	-	-	-	-	-	4 (8%)
Bar-Cohen, 2006	35 (37 crio)	29 (78%)	-	15/19 (79%) AS 9/12 (77%) MS 5/6 (83%) PS	-	-	-	-	13/29 (45%)

*data not available for 1 EAT ablation case; AVNRT = atrioventricular nodal re-entrant tachycardia; AVRT = atrioventricular re-entrant tachycardia; EAT = ectopic atrial tachycardia; VT = ventricular tachycardia; JET = junctional ectopic tachycardia; PS AP = posteroseptal accessory pathway; AS AP = anteroseptal accessory pathway; MS AP = midseptal accessory pathway.

the previous studies [56]. Drago *et al*. reported an acute success of 92%, without cryo-related complications or adverse outcomes, but with arrhythmia recurrence in the 29% of the acutely successful cases. The same authors reported, in a successive study, [57] an increased acute success rates (up to 100%) using a modified ablation protocol that required lengthier cryoablations plus delivery of a bonus cryoapplication to consolidate the acutely successful irreversible lesion created at intervention. Moreover, the modified protocol could also significantly improve the chronic success rate (90%).

The differing success rates achieved by various authors, adds to the interest of the data reported by Authors [58], who compared cryoablation with RF for the treatment of supraventricular arrhythmias in a single centre. Papez reported that, in his center, the acute success rate for cryoablation for AVNRT was comparable with that for RF (94% vs. 96%), although recurrence was greater (12% vs. 6%). Moreover the same author stated that the AVNRT cryoablation success rate seems to be increased by use of a 6 mm tip (100%). However, although the total success rate for APs was lower than with RF (75% vs. 92%), it was comparable for the midseptal and anteroseptal pathways – i.e. those closest to the His bundle. This confirms our opinion that cryoablation should be used specifically for the circuits closest to the AV junction. In AVNRT patients, Papez proceeded to cryoablation only after cryomapping had demonstrated the lack of AV conduction in the slow pathway and, in the accessory pathways, disappearance of the delta wave or of ventriculoatrial retrograde conduction.

Collins *et al*. [59] also compared his centre's results for RF transcatheter ablation and cryoablation of AVNRT. Sixty children were treated with RF and 55 with cryoablation, using a 4 mm cryocatheter tip. Almost all cryoablation patients were treated during sinus rhythm and without isoproterenol infusion. Cryomapping was considered positive when the atrial stimulation test revealed a change in pulse conduction through the slow pathway and non-inducibility of tachycardia. Examination of the results reveals that the procedure's duration was lower than for RF, and the fluoroscopy time similar. The two procedures achieved a similar acute success rate (100% vs. 98%), with a slightly higher recurrence for cryoablation (8% vs. 2%). However, this difference was not statistically significant. No permanent AV block was seen in either group. In this case, the high cryoablation success rate was probably due to careful patient selection. In fact, cryoablation was not performed in some patients, as AVNRT could not be easily induced. In these cases RF ablation was used, exploiting its ability to induce junctional acceleration during the production of an effective lesion.

At this time, data published are still controversial regarding the permanent success of cryoablation. Several studies have shown success rate comparable with RF current application while additional studies have reported a lower success rate using cryoenergy. Further studies with larger study populations are necessary to use correctly cryoenergy. At the moment, the good success rate and complete absence of complications (see Table **2**) suggest us to use cryoenergy in ablation of accessory pathways very close to AV junction.

CONCLUSION

RF ablation as safe and effective treatment for many tachycardia substrates. The refinements of the technologies, such as increased computational power, decreased catheter size, and increased maneuverability are allowing us to extend indications in the pediatric population.

But, although RF ablation is highly successful, the success rate is not 100% and a risk of an inadvertent complete AV block still exists. To avoid it, for its higher safety features cryoablation should be considered as an alternative energy mode to RF current for the treatment of arrhythmias with re-entry circuits located near the AV junction.

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