

Original Article

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Catheter ablation of focal atrial tachycardia in children using three-dimensional electroanatomic mapping system: a 6-year single-centre experience

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Abstract

Objective: This study demonstrates the clinical and electrophysiological details of catheter ablation conducted in children with focal atrial tachycardia using three-dimensional electroanatomic mapping systems. **Patients and methods:** Electrophysiological procedures were performed using the EnSite™ system. **Results:** Between 2014 and 2020, 60 children (median age 12.01 years [16 days–18 years]; median weight 41.5 kg [3–98 kg]) with focal atrial tachycardia and treated with catheter ablation were evaluated retrospectively. Tachycardia-induced cardiomyopathy was developed in 15 patients (25%). Most of the focal atrial tachycardia foci were right-sided (75%), and more than one focus was found in four patients. Radiofrequency ablation was performed in 47 patients (irrigated radiofrequency ablation in seven cases), cryoablation in 9, and radiofrequency ablation and cryoablation in the same session in 4 patients. The median procedural time was 163.5 minutes (82–473 minutes). Fluoroscopy was used in 29 of (48.3%) patients (especially for left-side substrate) with a mean time of 8.6 ± 6.2 minutes. The acute success rate was 95%. The procedure failed in three patients, and recurrence was observed in 3.5% of patients (2/57) during a median follow-up of 17 months (2–69 months). The second ablation was performed in four cases, of which three were successful. Overall success rate was 96.6% with no major complications observed, except in one patient with minimal pericardial effusion. **Conclusion:** Catheter ablation seems to be an effective and safe treatment in focal atrial tachycardia. Electroanatomic mapping system can facilitate the ablation procedure and minimise radiation exposure.

Focal atrial tachycardia is a rare cause of supraventricular tachycardia in children, originating from automatic, rapidly firing, non-sinus foci within the atrium.^{1,2} Although this tachycardia is benign in most instances, it could lead to tachycardia-induced cardiomyopathy in incessant cases, albeit it is generally reversible with the control of the arrhythmia.^{3,4} Younger children generally respond to antiarrhythmic therapy and present a higher incidence of focal atrial tachycardia resolution; hence, pharmacological therapy is the recommended first-line treatment for focal atrial tachycardia in infants.⁵ In children ≥ 3 years, focal atrial tachycardia is unlikely to resolve spontaneously, and antiarrhythmic medications are usually ineffective.⁶ Hence, catheter ablation should be considered early, especially in older children with recurrent symptoms, incessant tachycardia, or tachycardia-induced cardiomyopathy that is refractory or intolerant to medical treatment.^{5,6} Three-dimensional electroanatomic mapping system provides more precise localisation of ectopic foci and successful catheter ablation with limited fluoroscopy.^{7,8} Although several studies reported that this system can significantly decrease or even eliminate fluoroscopy exposure during catheter ablation of the supraventricular tachycardia substrates,^{9,10} there is limited data regarding its use in focal atrial tachycardia ablation in children.^{11–14}

This study summarises the authors' experience with catheter ablation in focal atrial tachycardia that was performed using a three-dimensional surface electrode-based navigation system (EnSite™ Precision, St Jude/Abbott Medical, St Paul, MN, United States of America) for guidance with limited fluoroscopy in children. This is the largest paediatric series from a single centre evaluating the efficacy and safety of catheter ablation and limited fluoroscopy in focal atrial tachycardia.

Patients and methods

This study included 60 patients (18 females and 42 males) who were diagnosed with focal atrial tachycardia, and underwent electrophysiological study and catheter ablation procedure between

February, 2014 and February, 2020. Data regarding clinical characteristics, echocardiographic examination, ablation procedures, and follow-up were obtained from hospital records using the Filemaker database. This retrospective cohort study was approved by the Institutional Review Board, and informed consent was obtained from all patients.

Electrophysiological study and catheter ablation

All patients and/or their legal guardians consented to the procedure. Antiarrhythmic medications were discontinued for at least five half-lives before the electrophysiological studies. Three-dimensional surface electrode-based navigation system was used in all patients.

Depending on the patient's age, an electrophysiological study was performed either under local anaesthesia with mild sedation or under general anaesthesia without intubation. For left-sided foci, access to the left atrium was achieved via the patent foramen ovale or transseptal puncture. The procedure was started without fluoroscopy, and catheters were placed into the right atrium, coronary sinus, and right ventricle under the EnSite™ Precision system's guidance. Three-dimensional images of the anatomy of the superior and inferior vena cava, right atrium, coronary sinus, and right ventricle were obtained.

Electroanatomic mapping was performed with multi-polar catheters (decapolar or duodecapolar) during tachycardia and recording local electrogram findings from the atria. Activation mapping was performed by comparing "local activation time values" with a fixed atrial "A" value. Usually, the atrial signal at the proximal electrode of the coronary sinus catheter; more rarely, the atrial signal at the distal end of the transesophageal electrode was considered as "A" reference. The location of atrial focus was assessed by the prematurity of local atrial activation compared to the stable "A" reference. Colour-coded electroanatomical mapping was also helpful in coding the potential target sites in 3D geometry. On the colour scale, early activation was colour coded in white with the latest activation points coded in purple. During tachycardia, the window of interest was determined to reveal whether the tachycardia was macroreentrant or focal/microreentrant. In focal/microreentrant tachycardia, it was assumed that there was radial propagation from a small focus. Amongst the earliest signals, the points at which propagation began were considered as the foci, and fractionated electrograms were simultaneously searched. In addition, a pure negative deflection (QS pattern) of unipolar atrial electrogram was determined. Finally, voltage mapping was performed during sinus rhythm or atrial pacing, if appropriate, to identify endocardial scars or fibrosis, which were defined as areas with endocardial signals <0.1 Mv.

If an adequate spontaneous atrial activity was not present at the beginning of the procedure, standard atrial and ventricular pacing manoeuvres were conducted and orciprenaline bolus was administered to stimulate atrial ectopy when necessary.

Radiofrequency energy application was used in majority of the patients. A steerable radiofrequency catheter was used for mapping and energy delivery. Irrigated radiofrequency was used when standard radiofrequency failed or in cases with focal atrial tachycardia scar-related lesion. Fixed curve or steerable long sheaths were used in right atrial foci where catheter stabilisation was difficult during radiofrequency.

Cryoablation was performed using 7 F 6-mm-tip or 9 F 8-mm-tip catheters (Medtronic, Minneapolis, MN, United States of America) in patients with foci close to the atrioventricular node and phrenic nerve.

All data regarding ablation procedures, numbers of lesions, extra arrhythmia substrates, and complications were recorded. After successful ablation, patients were observed for a 30-minute waiting period. The possibility of recurrence was assessed using pacing manoeuvres, and with orciprenaline or adenosine in some cases. When additional tachycardia mechanisms were deemed to have potential clinical relevance, mapping and ablation procedures were repeated.

Follow-up

As per standard practice, all patients underwent continuous telemetry monitoring, 12-lead electrocardiogram, 24-hour ambulatory electrocardiogram, and echocardiography before discharge. All patients were hospitalised following the ablation procedure as required by standard practice. They were examined at the outpatient clinic for symptoms suggestive of arrhythmia after 1, 3, and 6 months of the procedure and then every 12 months. At each visit, a 12-lead electrocardiogram, and if necessary, a 24-hour ambulatory electrocardiogram monitoring were performed. Recurrence was defined as the relapse of clinical symptoms consistent with episodes before the ablation, as well as documented focal atrial tachycardia with an electrocardiogram, a 24-hour ambulatory electrocardiogram, or an event recorder.

Statistical analysis

Statistical Package for the Social Sciences version 21.0 was used to analyse the data. Descriptive features were represented as percentages and mean \pm standard deviation or as median according to the distribution of the data determined by the Kolmogorov–Smirnov test. The data were compared using χ^2 or Fisher's exact tests and independent t-test or Mann–Whitney U-test depending on the distribution of the data. P-values <0.05 were considered statistically significant.

Results

General observations

All demographic and clinical characteristics of the included patients are listed in Table 1. During the study period, 60 patients underwent electrophysiological study for symptomatic focal atrial tachycardia. The median age of the patients (42 males and 18 females) was 12.01 years (16 days–18 years). Seven (11.6%) patients were aged <1 year, and two of them were newborns during the procedure. The children aged <1 year in this study had tachycardia complicated by drug resistance, drug intolerance, or tachycardia-induced cardiomyopathy, despite treatment with two or more antiarrhythmic drugs. The median weight of the patients was 41.5 kg (3–98 kg). CHD was present in 12 of (20%) patients, while focal atrial tachycardia with tachycardia-induced cardiomyopathy was found in 15 (25%). The mean ejection fraction in these patients was 39% (20–45). Before undergoing electrophysiological study, 8 patients (13.3%) were not under any regular antiarrhythmic medication, 23 (38.3%) were regularly taking 1 antiarrhythmic drug (beta blocker or class 1c antiarrhythmic), 17 (28.3%) were taking 2 different antiarrhythmic drugs (beta blocker + class 1c/class 3 antiarrhythmic [amiodarone/sotalol]), and 12 (20%) were taking 3 different antiarrhythmic drugs (beta blocker + class 1c + class 3 antiarrhythmic [amiodarone/sotalol]). Of the 60 patients, 5 (8.3%) had undergone previous

Table 1. Demographic and clinical characteristics of patients.

Characteristics	n = 60
Age, years, median (range)	12.01 (0.09–18)
Male	42 (70)
Weight	41.5 (3–98)
No CHD	48 (80)
CHD	
Atrial septal defect	6 (10)
Ebstein's anomaly	3 (5.1)
Left ventricular non-compaction cardiomyopathy	2 (3.3)
Fontan operation(tricuspid atresia)	1 (1.7)
Tachycardia-induced cardiomyopathy	15 (25)
Coexisting tachycardias	13 (21.7)
Atrioventricular nodal re-entrant tachycardia	6
Intra-atrial re-entrant tachycardia	2
Junctional ectopic tachycardia	2
Atrial flutter	1
Wolf–Parkinson–White syndrome	1
Frequent premature ventricular contraction	1
Medical therapy before ablation, n (%)	
No medication	8 (13.3)
Beta blocker or class 1c antiarrhythmic	23 (38.3)
Beta blocker + class 1c/class 3 (amiodarone/sotalol)	17 (28.3)
Beta blocker + class 1c + class 3 (amiodarone/sotalol)	12 (20)

n (%) and shortening fraction <28 or ejection fraction <50 and left ventricular end diastolic diameter z-score >2.

electrophysiological study at different institutions. Furthermore, 13 (21.7%) patients had other coexisting tachycardia conditions in addition to the focal atrial tachycardia, including typical atrioventricular nodal re-entrant tachycardia (n = 6), intra-atrial re-entrant tachycardia (n = 2), atrial flutter (n = 1), junctional ectopic tachycardia (n = 2), frequent premature ventricular contraction (n = 1), and Wolf–Parkinson–White syndrome (n = 1). All 13 patients underwent concurrent ablation for the other tachycardia conditions.

Number and localisation of focal atrial tachycardia foci

The anatomic localisation of the focal atrial tachycardia foci in this study is depicted in Fig 1. Amongst the 60 patients, 4 had 2 foci (60 patients, 64 arrhythmia foci). During the procedure, it was found that 45 of the focal atrial tachycardia foci were right-sided and 18 were left-sided. One case presented focal atrial tachycardia foci in both atria. Right-sided foci were located in clusters around the coronary sinus ostium (n = 11, 24.4%), along the crista terminalis (n = 10, 22.2%), tricuspid annulus (n = 9, 20%), and in or close to the right atrial appendage (n = 7, 15.5%). Left-sided foci were mainly found around the mitral annulus (n = 11, 57.8%) and pulmonary vein orifices (n = 5, 26.3%).

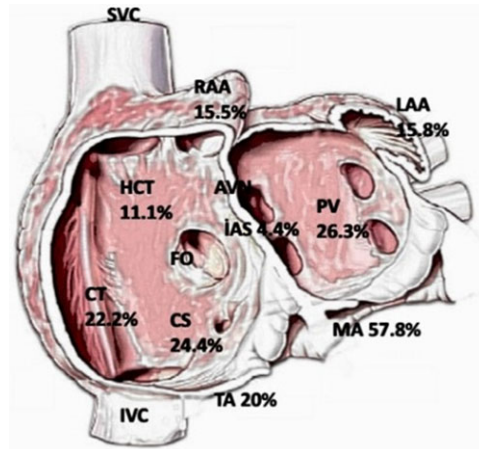


Figure 1. Anatomic location: a schematic representation of atrial ectopic foci distribution in the study population. AVN = atrioventricular node; CS = coronary sinus; CT = crista terminalis; FO = fossa ovalis; HCT = high crista terminalis; IAS = interatrial septum; IVC = inferior vena cava; LAA = left atrial appendage; MA = mitral annulus; PVs = pulmonary veins; RAA = right atrial appendage; SVC = superior vena cava; TA = tricuspid annulus.

Procedure characteristics

Procedural characteristics of the patients included in this study are listed in Table 2. After the electrophysiological study, radiofrequency ablation was performed in 47 patients (irrigated radiofrequency was performed simultaneously in 7 cases that did not respond favourably with radiofrequency, or when deep ablation lesion was required, or focal atrial tachycardia developed due to scar-related lesion), cryoablation was performed in 9 patients, and both radiofrequency and cryoablation were performed in 4 patients. The median procedural time was 163.5 minutes (82–473 minutes), including a 30-minute waiting period.

Limited fluoroscopy exposure

Fluoroscopy is not often used unless transseptal puncture is needed, and especially in children weighing <10 kg or those with complex CHD whose catheter position needs to be confirmed. Fixed curve or steerable long sheaths were used in right atrial foci where catheter stabilisation was difficult. Additionally, limited fluoroscopy was used in these cases.

All electrophysiological procedures in this study were performed using the EnSite™ Precision system.

Fluoroscopy was used in 29 of the 60 patients (48.3%). The mean fluoroscopy time was 8.64 ± 6.2 minutes, and median fluoroscopy dosage was 1.4 mGy (0.35–6.67 mGy). Of the 29 patients undergoing fluoroscopy, 15 had left-sided and 1 had bilateral atrial tachycardia. Transseptal puncture was performed in 16 patients (Fig 2a–e). Before attempting the transseptal puncture, the presence of patent foramen ovale was investigated using the previously generated three-dimensional model as a reference. If it was present, the left atrium was accessed through the foramen ovale. Mean fluoroscopy time during transseptal puncture was 3.67 ± 1.7 minutes. In the other patients <1 year of age or those with complex CHDs, fluoroscopy was used for catheter position determination. The mean fluoroscopy time was 9.14 ± 8.1 minutes in those with left-origin focal atrial tachycardia, and 8.1 ± 3.59 minutes in those with right-origin focal atrial tachycardia ($p = 0.672$). Comparative data between patients with left or right-side-originated foci of focal atrial tachycardia are presented in Table 3.

Table 2. Procedural characteristics and results of ablation.

Characteristics	n = 60
*The location of ectopic foci n (%)	
Right-sided	41 (68.3)
Left-sided	18 (30)
Both sided	1 (1.7)
Ablation methods n (%)	
Radiofrequency ablation (standard and/or irrigated tip)	47 (78)
Cryoablation	9 (15)
Both (radiofrequency ablation and cryoablation)	4 (7)
Acute success rate	57 (95)
Complication	1 (1.7)
Follow-up duration (months)	17 (2–69)
Recurrence at follow-up	2 (3.5)
Repeat ablation	3 (7)
Final success	58 (96.6)
Procedure time (minutes)	163.5 (82–473)
Number of patients using fluoroscopy	29 (48.3)
Fluoroscopy time (minutes)**	8.6 ± 6.2
Fluoroscopy time during transseptal puncture (minutes)**	3.67 ± 1.7
Flouro dosage (Mgy)	1.4 (0.35–6.67)

Median (range) and n (%)

*1> ectopic focus; right-sided n = 3 and left-sided n = 1

**mean

Success, complications, and follow-up

Acute success was achieved in 57 out of the 60 patients (95%). Successful ablation could not be achieved in three patients, of which right-sided focal atrial tachycardia was seen in two patients (one at the crista terminalis and one at the high crista terminalis) and left-sided in one (mitral annulus).

During a median follow-up of 17 months (2–69 months), two patients (3.5%) experienced recurrence, and both recurrences occurred within the first 6 months after ablation. The location of focal atrial tachycardia in these two patients was at the right appendage in one and at the orifice of the pulmonary vein in the other. Medical therapy was administered in one of these two patients (beta blocker and propafenone) because his symptoms could be controlled by medical treatment. Ablation was performed for the second time in one patient with recurrence and three patients in whom the procedure had previously failed, and three of these cases reported success. In one patient, radiofrequency ablation was unsuccessful because the tachycardia focus was located epicardially in the right atrium. The final success rate was 96.6%. Minimal pericardial effusion was observed in one patient, which did not require intervention. No other major complications were seen. Significant improvement in the left ventricular function was observed after successful ablation in patients who developed tachycardia-induced cardiomyopathy. The follow-up revealed that all patients showed normal left ventricular function in 6 months.

Discussion

This is the largest paediatric study evaluating the efficacy and safety of catheter ablation using three-dimensional electroanatomical mapping in children with focal atrial tachycardia from a single centre. The most noteworthy findings were as follows:

- Catheter ablation of focal atrial tachycardia in children, including infants, can be performed safely and effectively with limited fluoroscopy using three-dimensional electroanatomical mapping systems.
- A significant number of patients with tachycardia-induced cardiomyopathy showed normalised cardiac functions after successful focal atrial tachycardia ablation.
- Irrigated type radiofrequency ablation catheters can be safely used in children when deeper and larger ablation lesions are needed in the atrial tissue.

Focal atrial tachycardia is a rare cause of supraventricular tachycardia in children, which accounts for 5–10% of supraventricular tachycardia cases in adults, with higher rates seen in children.² Medical therapy has been the primary treatment for focal atrial tachycardia, especially in young children who are more likely to have spontaneous resolution.^{6,15,16} In children aged ≥ 3 years, focal atrial tachycardia is unlikely to resolve spontaneously, and antiarrhythmic medications are usually ineffective.⁶ Therefore, catheter ablation of focal atrial tachycardia is considered as the first-line therapy in patients with recurrent symptoms, conditions refractory to medical treatment, or incessant tachycardia or tachycardia-induced cardiomyopathy.^{17,18}

There is limited data regarding the use of catheter ablation for focal atrial tachycardia in younger children. Initial studies of radiofrequency ablation in young or small children suggested that there might be a lower success and higher complication rates. However, subsequent literature showed better outcomes of the procedure when performed with electroanatomical mapping as compared to the conventional strategy in terms of acute success rate and recurrences.^{12,13} Toyohara et al reported acute success in all of their paediatric focal atrial tachycardia patients (35/35) and 11% recurrence in patients undergoing radiofrequency ablation using the three-dimensional mapping system.¹⁰ Dieks et al reported acute success in 14 of the 16 patients (87.5%) using modern mapping systems.¹¹ Elkran et al reported acute success in 34 of the 39 patients (87.2%).¹⁴ In this study, acute success was achieved in 57 of the 60 patients (95%). During a median follow-up of 17 months (2–69 months), focal atrial tachycardia recurred in two patients (3.5%). Ablation was performed for the second time in one patient with recurrence and three patients in whom the procedure had previously failed. Of these cases undergoing the repeat procedure, three cases were successful. In one patient, radiofrequency ablation was unsuccessful because the tachycardia focus was located epicardially in the right atrium. The final success rate was 96.6%.

Although a 4 mm tip radiofrequency ablation catheter is adequate to ablate the arrhythmia focus located near the endocardium, it does not readily ablate the deeper tachyarrhythmia substrate. With 8- and 10 mm tip radiofrequency ablation electrodes, the ablation lesions are larger, but these catheters are associated with increased risk of coagulum, char, and thrombus formation, as well as myocardial steam rupture. Irrigated radiofrequency ablation tips prevent excessive temperatures at the electrode tip–tissue interface, and thus allow continued delivery of the radiofrequency current into the surrounding tissue. This

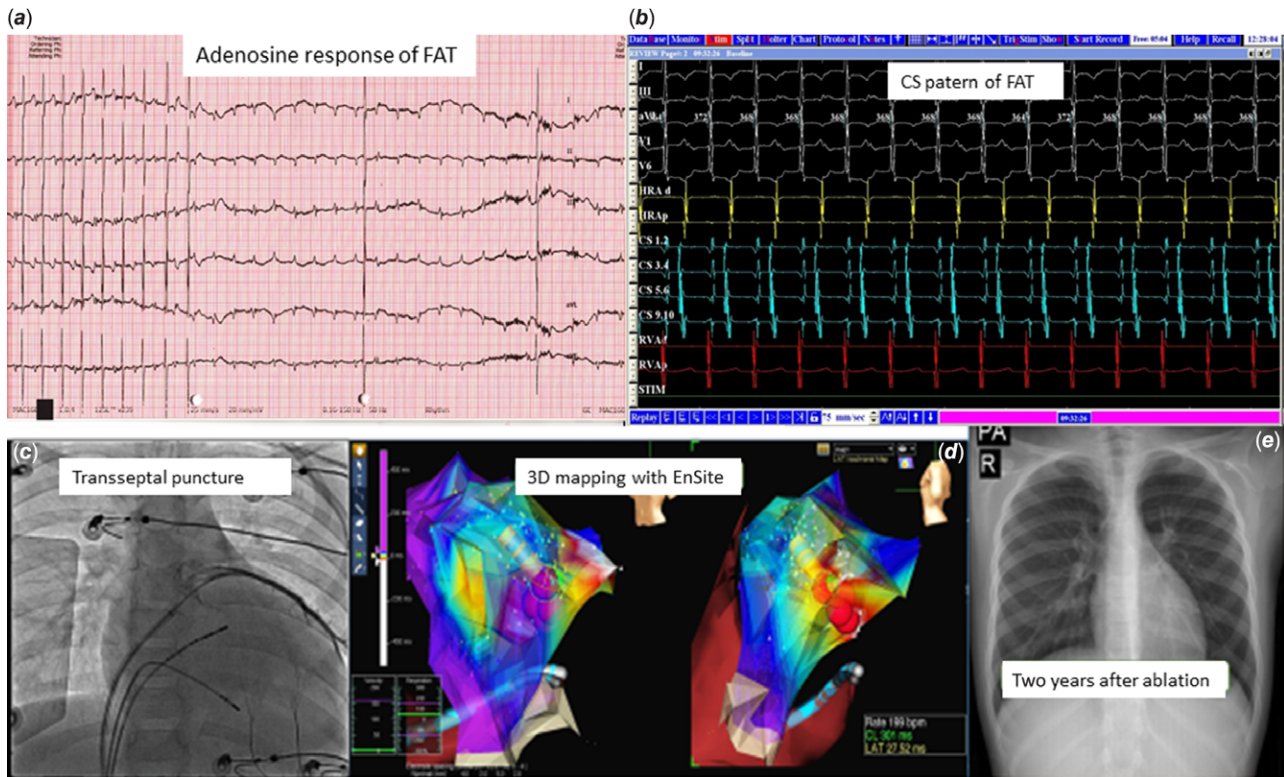


Figure 2. (a) During FAT, atrial p-waves appear on the ground with the AV block effect of IV adenosine. (b) During the electrophysiological study, the a-waves appear distally in the distal front of the diagnostic coronary sinus (CS) catheter (eccentric pattern; from the left). (c) Fluoroscopy image taken during the patient’s EPS ablation procedure (cardiomegaly due to tachycardia-induced cardiomyopathy is remarkable). (d) During EPS ablation, centrifugal propagation of the focal atrial tachycardia originating from left atrial appendage–left anterolateral annulus junction in 3D electroanatomic mapping with EnSite Precision (St Jude Medical Inc.) (e) Two-years after successful ablation, cardiomegaly completely improved in the patient’s telecardiography.

Table 3. Comparative data between patients with left or right-side-originated foci of focal atrial tachycardia**.

	Right (n = 41)	Left (n = 18)	p-value
Age, years	11.1 (0.13–18)	8.6 (0.09–16.49)	0.116
Weight, kg	41 (3–79)	34 (4–98)	0.173
Gender male	29 (66)	12 (70)	0.517
General anaesthesia	35 (85)	17 (94)	0.412
Additional arrhythmia	12 (29)	2 (11)	0.189
Tachycardia-induced cardiomyopathy	9 (22)	6 (33)	0.355
Cryoablation	13 (32)	–	0.006
Radiofrequency ablation	32 (78)	18 (100)	0.045
Irrigated radiofrequency ablation	4 (10)	3 (17)	0.451
Acute success	39 (95.1)	17 (94.4)	0.991
Procedure time	167(82–327)	207 (100–473)	0.014
Fluoroscopy time*	8.1 ± 3.59	9.14 ± 8.1	0.672
Complication	1(2.4)	–	0.991

Median (range) and n (%)

*mean

**The patient with focal atrial tachycardia foci in both atria is not included in the table.

ablation system creates larger and deeper ablation lesions and minimises steam pops and thrombus formation.¹⁹ In this study, irrigated radiofrequency ablation was used in seven cases that did not get sufficient current with standard radiofrequency ablation. There were no complications observed in the procedures where irrigated radiofrequency ablation was used. Highly acute and long-term success rates reported in this study could be associated with the use of irrigated radiofrequency ablation. Hence, irrigated tip catheters should be considered as adjunct tools when needed. Triedman et al pointed out that the extent of lesion depth limits the clinical success of ablation outcomes, and the use of irrigated ablation may result in improved rates of acute success with ablation.²⁰

It is well recognised that focal atrial tachycardia foci do not occur randomly throughout the atria, but tend to cluster at characteristic anatomic locations.²¹ As described by Lee et al,²² the most common site of focal atrial tachycardia foci in adult patients is the right atrium (75%), with the most common origin areas being the superior and middle parts of the crista terminalis. In the left atrium, foci are most often noted at the ostium of the pulmonary veins.²² Additionally, ectopic foci were found predominantly in the right atrium in the present study, mostly as clusters around the coronary sinus ostium along the crista terminalis and tricuspid annulus. Left-sided foci were mainly found around the mitral annulus and pulmonary vein orifices. These findings corroborated with the data from the previous studies.^{6,11} The location of focal atrial

tachycardia foci clusters differs between paediatric and adult patients. Lee et al reported that foci around the atrial appendage were rare in adult patients (0.6%).²² Toyohara et al demonstrated that in children aged <7 years, ectopic foci were mostly localised in the left and right appendages, because of the presence of residual embryonic tissue.¹⁰ In this study, the percentage of foci around the right and atrial appendages were 15.5 and 15.8%, respectively. Toyohara et al also demonstrated that patients with crista terminalis-related focal atrial tachycardia were aged >7 years, suggesting that the substrate of focal atrial tachycardia originating in the crista terminalis might be acquired with age.¹⁰ In this study, the mean age of the patients with crista terminalis-related focal atrial tachycardia was 12.4 years.

A longer procedural time duration was observed in the left-sided focal atrial tachycardia ablations as compared to the right-sided ones in the present study. However, existing literature shows that the total procedural time duration in this study was shorter than that of other studies (median procedural time = 163.5 minutes [82–473 minutes]).^{11,12} The procedural time in the left-sided cases was slightly longer because of the time needed to catheterise the left atrium either through a patent foramen ovale or through a transseptal puncture in case of the absence of a patent foramen ovale. Although the procedural time was longer in those with left-sided focal atrial tachycardia foci, no significant difference between the fluoroscopy time was observed ($p = 0.672$).

Systolic dysfunction associated with chronic tachyarrhythmia is known as tachycardia-induced cardiomyopathy.^{4,23} Of the 60 patients in this study, 15 (25%) presented with decreased ventricular function and tachycardia-induced myopathy, an incidence rate similar to that reported in the literature.^{10,12} At the same time, these findings did not show a significant difference in the development of tachycardia-induced myopathy between the right- and left-sided focal atrial tachycardia cases ($p = 0.355$). Children with focal atrial tachycardia are less likely to be aware of palpitations and tachycardia episodes.¹⁰ Hence, the complication of focal atrial tachycardia with tachycardia-induced myopathy was more commonly observed in children than in adults. Medi et al reported a 10% incidence of tachycardia-induced myopathy with focal atrial tachycardia in adults.⁴ In this study, 6 (40%) of the patients who developed tachycardia-induced myopathy were aged <1 year. The left ventricular function returned to normal or near-normal in all patients with tachycardia-induced myopathy during the follow-up. Medi et al reported that patients with rapid focal atrial tachycardia could, therefore, be recognised earlier and given quick treatment, leaving less time for tachycardia-induced myopathy to develop. In contrast, patients with slower incessant tachycardia may not present palpitations early on, but rather later with symptoms of cardiac failure.⁴

Children undergoing conventional radiofrequency ablation are believed to be at increased risk of developing malignancy caused by radiation exposure.²⁴ The increased lifetime risk of fatal malignancy was 0.02% with each radiofrequency ablation procedure.²⁴ Thus, non-fluoroscopic or limited fluoroscopy electroanatomical mapping systems have become a focus of current research. In the present study, the mean fluoroscopy times (mean 8.64 ± 6.2 minutes) was significantly reduced with the routine use of modern three-dimensional mapping systems compared to previous studies.^{11,12} Cummings et al compared two-dimensional and three-dimensional mapping and found no significant differences in the fluoroscopy times (47 ± 24 versus 40 ± 20 minutes). Dieks et al reported that their median fluoroscopy time was 13.1 minutes (4.5–22.5 minutes) for focal

atrial tachycardia ablation with three-dimensional mapping systems in children. In one of the largest studies on the current management of paediatric focal atrial tachycardia, 134 patients (54%) underwent 167 catheter ablation procedures, with median fluoroscopy time of 23 minutes (95% confidence interval, 20–30).¹³ Fluoroscopy was performed in 29 of our patients for transseptal puncture or catheter position detection, especially in young children weighing <10 kg. The mean fluoroscopy time during transseptal puncture in this study was 3.67 ± 1.7 minutes. Although the procedural time in this study was longer in left-sided ablations, no significant difference between the left and right fluoroscopy times was found ($p = 0.672$).

Depending on the age, major complications have been reported during focal atrial tachycardia ablation in 3–8% of the cases.²⁵ Reported complications include 2° and/or 3° atrioventricular block, perforation, pericardial effusion, thrombus formation, damage to phrenic nerve, stroke, and cardiac arrest. In this study, minimal pericardial effusion was observed in one patient, which did not require intervention. No other major complications were seen.

Catheter ablation can be performed effectively and safely in paediatric focal atrial tachycardia patients, including infants, using a limited fluoroscopic approach with the help of an electroanatomical mapping system. Irrigated radiofrequency ablation should be considered as an alternate method in deep lesions or scar-related lesions, where sufficient current cannot be provided with standard radiofrequency ablation.

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Conflicts of interest. All authors declare that they have no conflict of interest.

Ethical standards. The authors assert that all procedures contributing to this work comply with the ethical standards of the institutional research committee (Approval number: 2020/34) and with the Helsinki declaration of 1975, as revised in 2008, and has been approved by the institutional committees.

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