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# Preventing the risk of coronary injury in posteroseptal accessory pathway ablation in children: different strategies and advantages of fluoroscopy integrated 3D-mapping system (CARTO-UNIVU™)

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**Abstract**

**Purpose** To evaluate various strategies in order to minimize the risk of coronary injury during posteroseptal accessory pathways ablation in children.

**Methods** We retrospectively reviewed 68 posteroseptal accessory pathways ablation procedures (20 decremental and 48 typical accessory pathways) performed in 62 pediatric patients at our institution between July 2009 and December 2016. Only posteroseptal accessory pathways targeted near or within the coronary sinus were included and ablation was mostly performed using irrigated tip radiofrequency.

**Results** Median patient age was 11 years with a median body weight of 39 kg. Thirty patients underwent a coronary angiogram, 21 were coupled to the 3D navigation system CARTO-UNIVU™. The coronary angiogram showed a distance of less than 5 mm between the coronary artery and the ablation site in 40% of our cases; 3 patients had a coronary injury related to RF ablation, 6 patients were switched for cryoablation, 3 patients received limited RF energy (20 W). There were no demographic data predicting the proximity of the coronary artery to the ablation site.

**Conclusion** Ablation of posteroseptal accessory pathways specifically in children carries a risk of coronary artery injury which is probably underestimated. The use of merged 3D images and coronary angiograms, the reduction of RF energy or the switch to cryoablation are possible alternatives to limit the risk of coronary injury.

**Keywords** Posteroseptal accessory pathway · Catheter ablation · Coronary artery injury · Coronary sinus · Pediatric

## 1 Background

Catheter ablation has become a routine treatment option with high success rates and few complications in the management of pediatric patients with accessory pathways (APs) [1, 2]. The registry of the Pediatric Electrophysiology Society has shown that outcome in terms of complications and recurrence varies according to the location of the AP [1]. When APs are located in the posteroseptal (PsAP) region however, catheter ablation can be more complicated and is associated with higher rates of recurrence, and AV block and potential risk of coronary artery lesions due to RF energy application within the coronary sinus (CS) [3, 4].

Even though the occurrence of coronary injury has been described after PsAP ablation in the CS both in adult and pediatric patients, this complication seems to be largely underestimated [5, 6]. Only a few cases of acute or delayed coronary artery damage in pediatric patients have been reported [6, 7]. Given the constraints related to the small size of pediatric hearts and the close vicinity of the coronary artery to the site of ablation, it is surprising that reports of this complication remain scarce.

In order to minimize the risk of coronary injury, various strategies based on local experience have been proposed but never evaluated. Current practices include

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performing a coronary angiogram, using non-irrigated RF with close monitoring of the electrocardiographic ST changes, or cryoablation when the coronary angiogram shows a distance of less than 5 mm between the ablation site and the coronary artery or when ST changes are observed. This approach has some limitations because, in the absence of cooling, the temperature rise can preclude RF energy delivery in the CS. On the other hand, mapping can be difficult with cryoablation due to the stiffness of the catheter. We report our experience of epicardial PsAPs catheter ablation in children using non-irrigated RF (RFni), cryoablation (Cryo) but also irrigated RF (RFi) catheter, in combination with the CARTO-UNIVU™ system in order to integrate the coronary angiogram.

## 2 Objective

The aim of this study is to evaluate the outcome of PsAP catheter ablation within the coronary sinus using various sources of energy and coronary angiogram integration within the 3D mapping system.

## 3 Methods

This is a retrospective cohort study based on the clinical records of patients aged < 18 years who underwent an electrophysiological study in our institution between July 2009 and December 2016. Data were collected from existing medical records after approval of the local Ethics Committee.

### 3.1 Posteroseptal accessory pathway

Posteroseptal APs are defined as APs located posterior or apical to the coronary sinus orifice, having a right or left insertion and typical accessory pathway characteristics or decremental retrograde conduction as in permanent junctional reciprocating tachycardia (PJRT). Only the PsAPs which were targeted near or within the coronary sinus were included in this study.

### 3.2 Electrophysiological study and catheter ablation

An electrophysiological study was performed under general anesthesia. Ablation was performed using standard RF (RFni) (Celsius, Biosense Webter) or an irrigated electrode catheter (RFi) (Thermocool, Biosense Webster) with delivery power of between 15 and 30 W or cryoablation (Cryo) using cryocatheter (Freezor 1™, Medtronic). After an observation period of 20 min, ablation was considered successful if neither reciprocating tachycardia could be induced at rest or with isoprenaline, nor persistent retrograde or anterograde conduction via the typical accessory pathway was noticed at baseline or after adenosine infusion.

After the procedure, all patients underwent continuous telemetry and Holter ECG monitoring for 24 h and an ECG at 1 h and 1-day post-ablation.

### 3.3 Coronary angiogram

Our local strategy of performing a coronary artery angiogram has changed over time according to our experience and to published data (Fig. 1). Angiograms were obtained in at least two perpendicular projections using small amounts of hand-injected contrast media.

Between July 2009 and March 2015, a coronary angiogram was systematically performed for PsAP ablation in children aged < 5 years and weighing less than 25 kg. Since March 2015, a coronary angiogram has been performed in all children referred for a PsAP ablation. Short after March 2015, a software system was implemented (CARTO-UNIVU™, Biosense Webster) which allowed the combination of a static fluoroscopy image from the coronary angiogram with an electroanatomical image.

Depending on coronary dominancy either the posterolateral branch of the right coronary artery (right dominancy) or the circumflex artery (left dominancy) is in close proximity to the proximal part of the coronary sinus. The coronary artery was considered to be in close proximity to the ablation site if the distance between the CA and the catheter was <5 mm according to Stavrakis et al. [8].

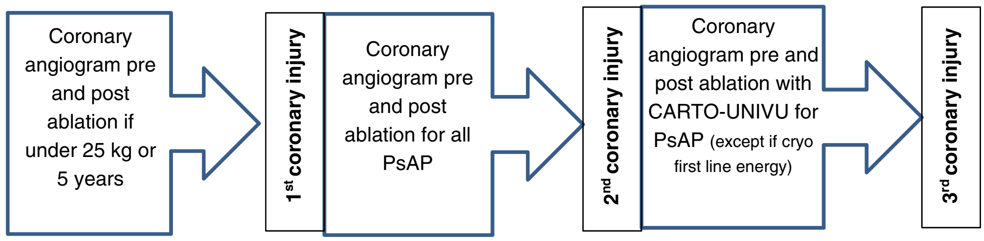
### 3.4 Immediate and mid-term success rate

Immediate success was determined at the end of the procedure. Mid-term success was defined as the absence of documented reciprocating tachycardia or WPW recurrence during the follow-up period.

All the patients had an ECG and a clinical appointment with a pediatric cardiologist at 1 month and 1-year post-ablation for typical APs. For PJRT patients, follow-up examination included a systematic Holter ECG at 1, 6, and 12 months.

### 3.5 Statistical analysis

Values are presented as mean ± SD for normally distributed continuous variables and median (interquartile range) for non-normally distributed variables. Values are presented as *n* (%) for categorical variables. Continuous variables were compared using Student's *t* test or the Mann-




| n | 43 | 1 | 24 |
|---|---|---|---|
| Coro | 7 | 1 | 21 with CARTO-UNIVU™ |
| RFi | 9 | 1 | 13 |
| RFni | 4 | 0 | 3 |
| Cryo | 0 | 0 | 6 |
| RFni+ Cryo | 0 | 0 | 2 |

**Fig. 1** Timeline illustrating our strategy regarding coronary angiography indication changes over time and complications. AP, accessory pathway; Coro, coronary angiogram; PS, posteroseptal; RFi, irrigated radiofrequency; RFni, non-irrigated radiofrequency

Whitney U test, as appropriate. Categorical variables were compared with Fisher's exact test. A $p$ value $< 0.05$ was considered statistically significant. All analyses were done using SPSS version 23.

## 4 Results

### 4.1 Population

Between July 2009 and December 2016, we performed 535 pediatric catheter ablations, of which 310 (58%) involved accessory pathways. A total of 68 PsAP (21%) ablation procedures (20 decremental APs and 48 typical APs) were performed in 62 children. The mean age at the time of ablation was 11 years (ranging from 3.9 to 18.9). Among the 62 patients, 71% were symptomatic: Thirty-seven presented with palpitations (60%), 4 with presyncope (7%), and 8 with heart failure (13%) due to tachycardia induced cardiomyopathy (all of whom where in the PJRT group). The remaining 18 (29%) were asymptomatic and referred to electrophysiological study due to the incidental finding of a preexcitation or a PJRT on their ECG. PJRT patients were significantly younger ($8.7 \pm 3.6$ vs. $12.7 \pm 3.5$, $p < 0.001$) and were had more frequently anti-arrhythmic drugs serious adverse events (25 vs. 0%, $p < 0.001$).

### 4.2 Catheter ablation

The PJRT and the typical APs subgroups were comparable in terms of procedure time, number and duration of RF applications, mean temperature, fluoroscopy time, and dose area product (Table 1).

The ideal site of ablation was located at the ostium of the CS or the proximal portion of the CS in 59 patients and 9 had both right and left RF applications. RF energy was used alone in 60 (88%) procedures with 53 RFi and 7 RFni. Cryoablation was used alone in 6 instances or associated with RF in 2 procedures.

**Table 1** Catheter ablation

| | Typical APs $n = 48$ | PJRT $n = 20$ | Total |
|---|---|---|---|
| Coronary angiogram ($n$) | 18 (37.5%) | 12 (60%) | 30 |
| CARTO-UNIVU ($n$) | 13 (27%) | 8 (40%) | 21 |
| Security margin | | | |
| ≤ 5 mm | 10 (20%) | 8 (40%) | 18 |
| > 5 mm | 8 (17%) | 4 (20%) | 12 |
| Unknown | 30 (63%) | 8 (40%) | 38 |
| Energy | | | |
| RFi | 36 (75%) | 17 (85%) | |
| RFni | 6 (13%) | 1 (5%) | |
| Cryo alone | 4 (8%) | 2 (10%) | |
| RFni + Cryo | 2 (4%) | 0 (0%) | |
| Intervention (min) | 94 ± 50 | 82 ± 21 | |
| Ablation | | | |
| Applications ($n$) | 11.7 ± 11.3 | 7.9 ± 4.8 | |
| Duration (sec) | 472 ± 350 | 478 ± 264 | |
| Radiofrequency | | | |
| Mean power (W) | 30 ± 6.2 | 28 ± 4.3 | |
| Mean temp (°C) | 40 ± 6.9 | 37 ± 6.1 | |
| Fluoroscopy | | | |
| PSD (cGy/cm2) | 236 ± 321 | 138 ± 100 | |
| Dose (mGy) | 34 ± 48 | 24 ± 18 | |
| Duration (min) | 11 ± 11 | 11 ± 6 | |

Values are presented as $n$ (%) or median (interquartile range)

*APs* accessory pathways, *RF* radiofrequency, *PSD* peak skin dose, *DAP* dose area product, *RFi* irrigated radiofrequency, *RFni* non-irrigated radiofrequency

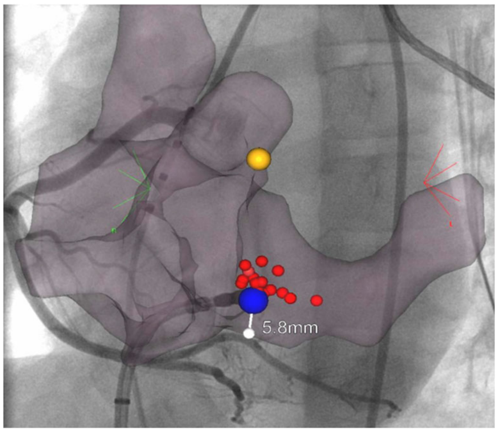



**Fig. 2** UNIVU image: merge of CARTO 3D and right coronary angiography showing a good security margin > 5 mm branches of the right coronary artery and the ablation catheter

### 4.3 Coronary angiogram and coronary artery injury

Coronary angiogram before and after RF ablation was performed in 29 procedures (43%) and in 1 patient after RFCA only. The CARTO-UNIVU™ system was used in 21 procedures providing a 3D analysis of the safety margin between RF catheter and CA throughout the whole procedure without additional fluoroscopy (Fig. 2).

Among the patients who underwent a coronary angiogram, there was a close proximity (< 5 mm) of coronary arteries to ablation site in 12 patients (19% of the population and 40% of the patients undergoing a coronary angiogram).

There were no demographic criteria predicting the proximity of CA to the ideal RF site in terms of age, weight, height, or BSA (Table 2).

Three coronary injuries occurred, the first two using irrigated tip catheters and one using a non-irrigated RF catheter.

**Patient 1** The first patient was a 9-year-old boy (BSA 1.19 m$^2$, 39 kg, 130 cm) presenting with drug refractory PJRT. He had no angiogram before ablation because he was not considered to be at risk regarding his age and weight. After RFi application at the roof of the ostium of the coronary sinus (5 RF pulses with a mean power of 30 W, mean temperature of 40 °C lasting for a total of 358 s), he presented with acute posterior STEMI on his ECG. Coronary angiogram showed an uncommon coronary disposition with the circumflex artery crossing the ostium of the CS which was occluded at its distal portion. Nitrates were ineffective and he immediately underwent percutaneous balloon angioplasty (Fig. 3). A cardiac MRI performed at day 1, showed a preserved LVEF of 50% with a transmural scar leading to inferobasal and septobasal akinesia with no viability. The results were stable at 6 months with a LVEF of 57%, and no PJRT recurrence.

**Patient 2** The other patient was an 8-year-old girl (BSA 0.82 m$^2$, 20 kg, 120 cm) presenting with drug refractory PJRT. Her conventional coronary angiogram before ablation showed a security margin > 5 mm between the supposed ideal ablation site and branch of the right coronary artery. PJRT could not be stopped by the initial RFi lesions so the RF catheter was slightly withdrawn from the initial site (14 RF pulses at a mean power of 25 W, mean temperature 35 °C and lasting for a total of 740 s). The control angiogram showed occlusion of RCA distal branches and the patient was asymptomatic with minor ECG modification. Given the small territory and the size of the vessel, no revascularisation was anticipated. Her MRI at day 1 after RF showed an EF of 56% with a limited inferobasal akinesia; MRI at 6 months showed no progression of the lesions and no SVT recurrence was reported (Fig. 4).

**Patient 3** The third patient was a 15-year-old girl (BSA 1.42 m$^2$, 46 kg, 157 cm) presenting with orthodromic reciprocating tachycardia. Exploration showed a benign PsAP. Her coronary angiogram coupled with CARTO-UNIVU™ before ablation showed a security margin of 7 mm between the ideal ablation site and trifurcation of the right coronary artery (Fig. 5). As the security

**Table 2** Comparison among the patients undergoing a coronary angiogram ($n = 30$) with a security margin > 5 mm vs. < 5 mm

| | Safety margin ≤5 mm $n = 18$ | Safety margin >5 mm $n = 12$ | *p* |
|---|---|---|---|
| Typical APs (*n*) | 10 (55.6%) | 8 (66.7%) | 0.189 |
| Male (*n*) | 11 (61.1%) | 8 (66.7%) | 0.091 |
| Age (years) | 10.4 ± 4.2 | 9.77 ± 2.7 | 0.640 |
| Weight (kg) | 37 ± 17 | 35 ± 13 | 0.758 |
| Height (cm) | 139 ± 24 | 142 ± 18 | 0.704 |
| BSA (m$^2$) | 1.18 ± 0.38 | 1.17 ± 0.29 | 0.933 |

Values are presented as *n* (%) or mean ± SD

*APs* accessory pathways, *BSA* body surface area

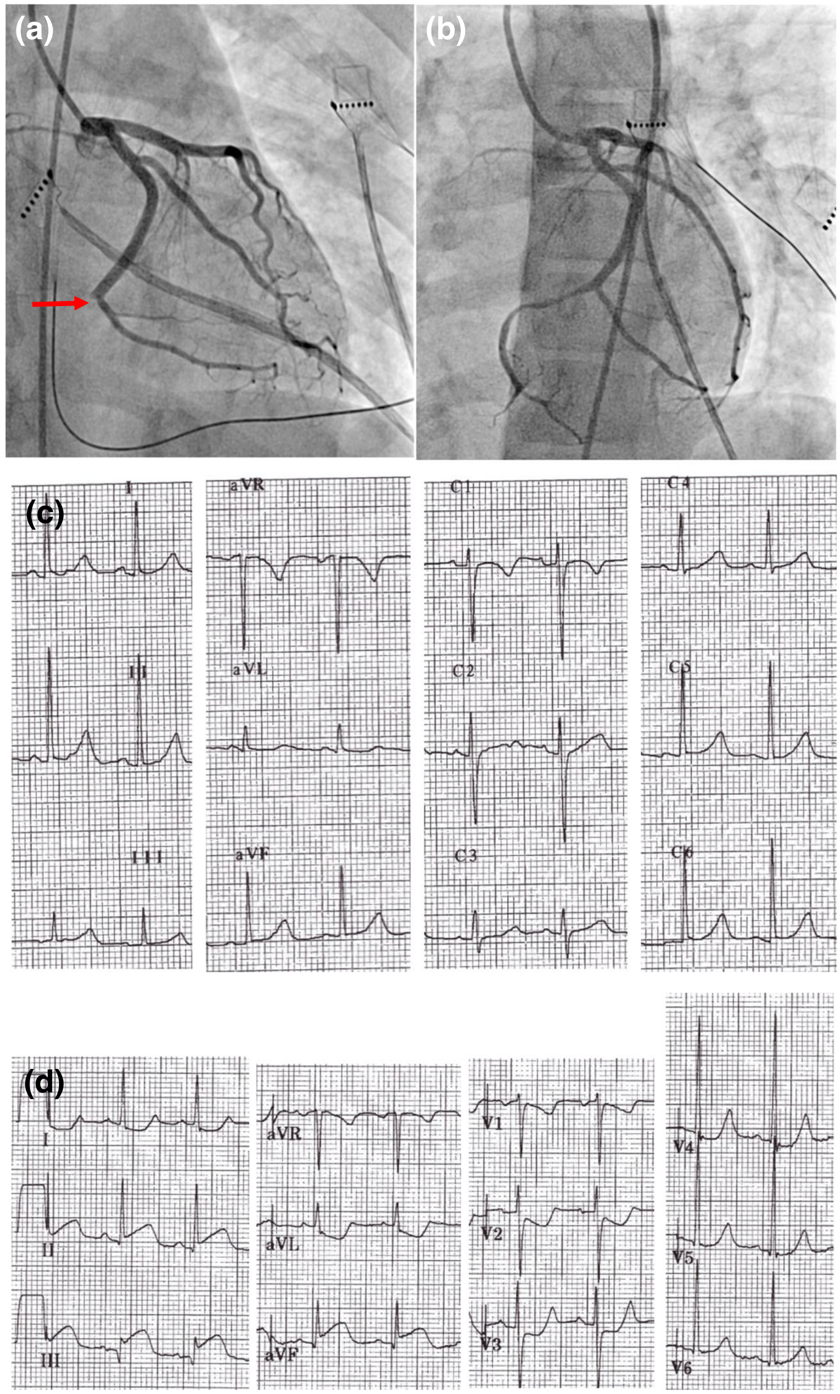



**Fig. 3** Left coronary angiography (**a**) showing a complete circumflex artery occlusion (arrow) after RF catheter ablation at the coronary sinus ostium (patient 1). The angiography was not performed prior to ablation in this patient, but after ST-segment changes. Control after balloon angioplasty (**b**). Normal baseline ECG (**c**). STEMI on immediate post-ablation ECG (**d**)

margin was above 5 mm, we proceeded with the ablation using RFni (23 RF pulses at a mean power of 30 W, mean temperature 55 °C and lasting 760 s). ECG modification appeared during the last application. The control angiogram after ablation showed occlusion of the posterior descending artery. She underwent immediate percutaneous balloon angioplasty with restoration of a TIMI 3 flux and normalization of the ECG. Cardiac MRI performed at day 1 showed a preserved LVEF at 57% with infero septobasal scar with viability. Six-month follow-up showed a LVEF of 57% with no modification of the ischemic lesion.

There was no significant difference in terms of RF energy, application duration, or mean ablation temperature between the 3 patients with CA injury and the rest of our cohort (Table 3). Among the 18 patients with a true safety margin (CA > 5 mm from the ablation site), no CA injury was reported. No coronary complication was observed with cryoablation. No complication related to coronary angiogram was reported as well as no AV block.

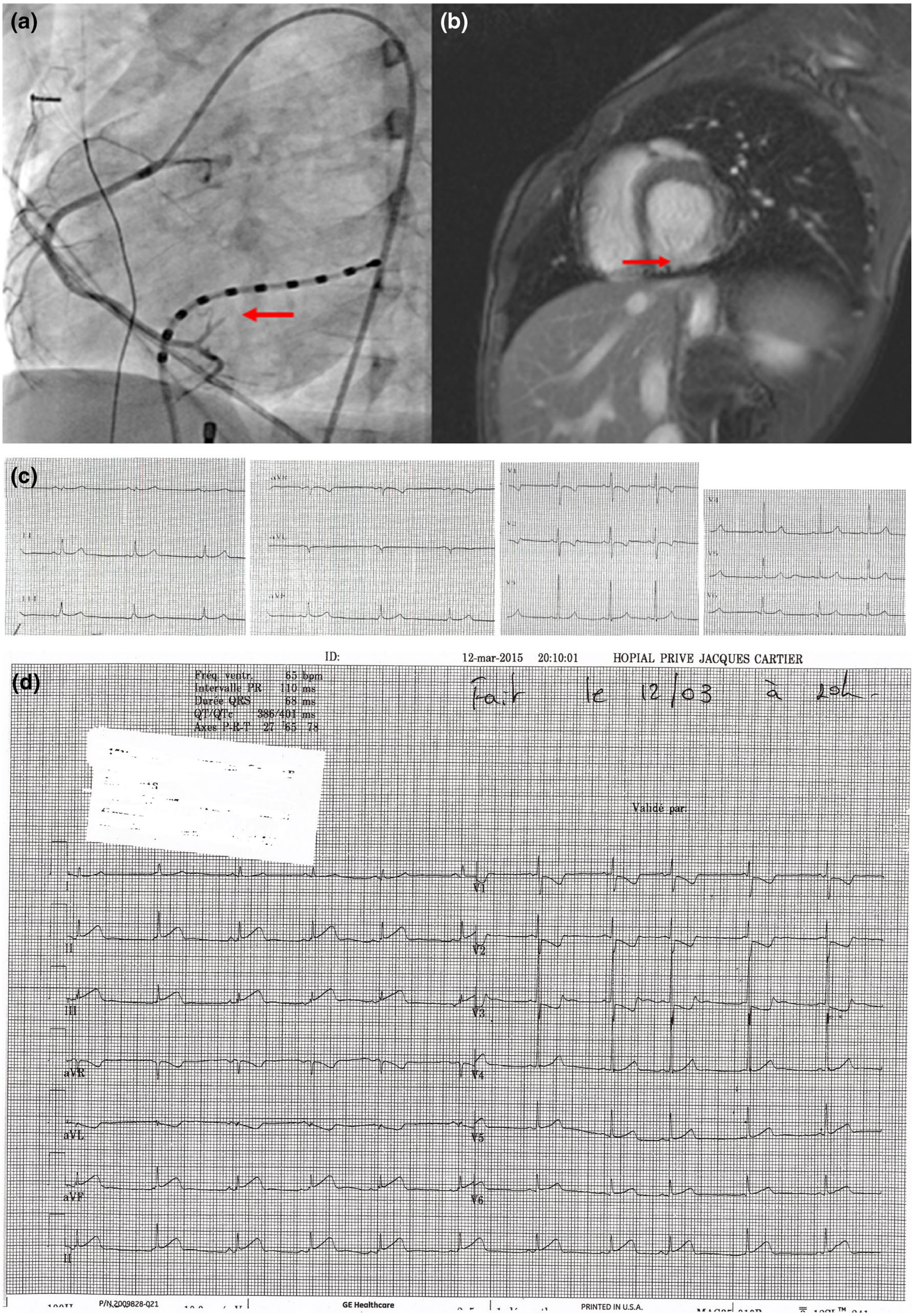



Fig. 4 Right coronary angiography (**a**) showing an occlusion of the posterolateral branch of the right coronary artery (patient 2). MRI at 6 months after ablation showing a limited inferobasal sequela (**b**). Normal ECG before ablation (**c**). ST modifications on the ECG after ablation (**d**)

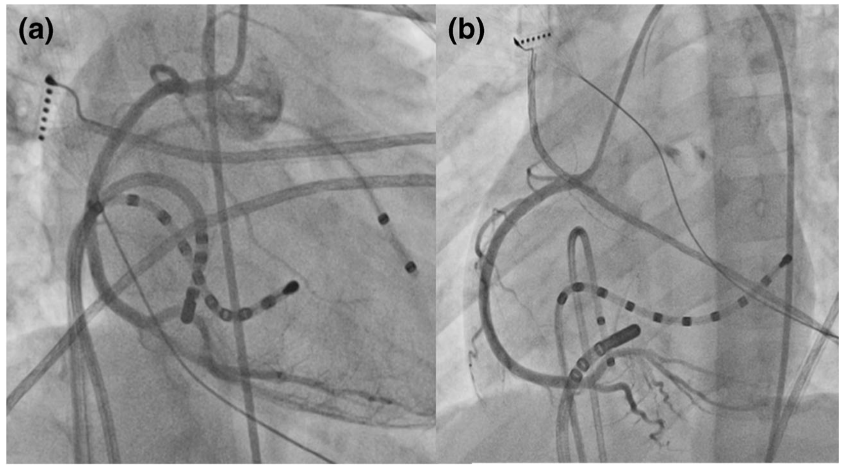



**Fig. 5** Right coronary angiography (**a**) showing an immediate proximity between the right coronary artery and the cryoablation catheter. Control after cryoablation ablation showing no lesions (**b**)

### 4.4 Immediate and mid-term success rate

The acute success rate was 81% for all patients at first ablation: 80% for typical APs and 79% for PJRT. All patients were followed up for 12 months; the late success rate was 80% for all procedures: 71% for typical APs and 95% for PJRT.

## 5 Discussion

The latest expert consensus statement on CA in the pediatric population published [9] specifies that for "*APs located in the coronary sinus, care should be taken to carefully delineate proximity to the coronary arteries to avoid inadvertent coronary damage*," but there is no clear recommendation on how to achieve this. Our study emphasizes the importance of a systematic coronary angiogram before and even after PsAP ablation attempts.

Schneider et al. report a series of 112 pediatric ablation procedures including 25 PsAPs and describe two cases of post-ablation stenosis after RFni application [6]. Both presented with PsAP and had a coronary angiogram prior to ablation. Taking into account the 25 PsAP, the rate of CA complication was 8% in this series. Mao et al. reported two CA injuries (8.6%) out of 23 posteroseptal APs ablations in adults using RFni [10].

The rate of 4% CA injury (3 out of 68 procedures) in our study is consistent with previous report. Nevertheless, we cannot exclude under-diagnosed coronary stenosis without significant ECG modification for the 38 patients who did not have a post-ablation coronary angiogram.

Coronary injury after RF ablation can be acute or delayed depending on its mechanism, as exhaustively reviewed by Castano et al. [11]. The major risk factor for CA lesion is the proximity of the coronary artery to the ablation site [11]. Indeed, Starvakis et al. demonstrated that the risk of coronary artery injury was directly correlated to the distance between the RF energy delivery site within coronary veins and the coronary artery. The incidence of CA injuries was as much as 50% if the distance was less than 2 mm, and 0% when the distance was above 5 mm [8]. One can expect that the risk of CA injury is more prevalent in the pediatric population given that the heart dimensions are smaller and CA are narrower with less convective cooling than adults [12]. In a series of 10 normal pediatric heart specimens, the distance between the endocardium and the coronary artery

**Table 3** Characteristics of patients with coronary artery lesions

| | Patient 1 | Patient 2 | Patient 3 | All Procedures $n = 68$ |
|---|---|---|---|---|
| Age (year) | 9.6 | 8.1 | 15.2 | 11.5 |
| Weight (kg) | 39 | 20 | 46 | 41 ± 17 |
| Height (cm) | 130 | 120 | 157 | 145 ± 1 |
| BSA ($m^2$) | 1.19 | 0.82 | 1.42 | 1.28 ± 0.36 |
| RF energy | RFi | RFi | RFni | |
| RF applications (*n*) | 5 | 14 | 23 | 10 ± 9 |
| RF appl. time (s) | 358 | 740 | 760 | 474 ± 322 |
| Mean power (W) | 30 | 25 | 30 | 30 ± 6 |
| Mean temperature (°C) | 40 | 35 | 50 | 40 ± 7 |

Values are presented as mean ± SD

*BSA* body surface area, *RFi* irrigated RF catheter, *RFni* non-irrigated RF catheter

Table 4 First ablation outcomes depending on energy use

| | Irrigated RF $n = 53$ | Non-irrigated RF $n = 9^{*}$ | Cryo $n = 6$ | $p$ |
|---|---|---|---|---|
| Acute success ($n$) | 42 (81%) | 7 (78%) | 4 (66.7%) | 0.819 |
| 1 year recurrence ($n$) | 11 (21%) | 1 (11%) | 2 (16%) | 0.567 |
| Coronary injury ($n$) | 2 (3.8%) | 1 (11%) | 0 (0%) | 0.724 |

Values are presented as $n$ (%)

*Cryo* cryoablation, *RF* radiofrequency

*Among non-irrigated RF, two patients were converted from cryoablation

was correlated with age. Moreover, the shortest distance was inside the coronary sinus and in the posteroseptal region, generally equal to or less than the depth of an RF lesion [13]. In concordance with Schneider's findings, our study found no demographic data that could predict the closeness of the CA to the coronary veins [8].

Surprisingly, the overall incidence of coronary injuries reported during ablation procedures of PsAP is low considering the incidence of this location (up to 25%) [1]. This is an issue which is possibly under-recognized and under-reported. Under-diagnosed chest pain in children may be due to sedation or could be mistaken as pericardial irritation, the distance between the CA and the effective ablation site can be shorter than initially estimated. Since ST modification is not always present, can be transient or can mimic a cardiac memory phenomenon after ablation of AP and since all biologic markers may be perturbed by the ablation, a coronary angiogram would appear to be also necessary after ablation.

The use of RFi within the coronary sinus in the pediatric population is debated. Compared to previous published data, the incidence of coronary injury in our study does not seem to be higher using RFi rather than RFni. Potential coronary injury could be more related to power intensity and lesion size than to irrigation per se, as suggested by Castano et al. [11].

To our knowledge, this is the first publication demonstrating the feasibility of irrigated tip RF ablation in the posteroseptal region in children when the distance between the coronary vein and the coronary artery is large enough. However, the safety margin may be difficult to assess.

Our experience suggests that a standard coronary angiogram with two perpendicular projections is not sufficient. Indeed, in some, not infrequent cases, the initial supposed ideal site is ineffective in stopping tachycardia, especially in the presence of wide or multiple atypical APs. Therefore, in such cases, the catheter is slightly dragged and the final RF application site can be closer to the CA than initially estimated, as illustrated by our patient 2. Coronary angiogram coupled to the CARTO-UNIVU™ system may be a better option since it allows a more precise and constant assessment of the security margin in a 3D reconstruction (Fig. 2). This system is consistent with the ALARA principle of reducing fluoroscopy levels for physicians, staff, and patients to as low as reasonably achievable. Our study is the first of its kind to provide a 3D comprehensive anatomical using coronary angiography integrated into the CARTO-UNIVU™ System for accessory pathways' ablation in children. However, this tool has some limitations as well as its own learning curve. A coronary computed tomography angiography might be an alternative to assess the relationship between coronary arteries and coronary sinus, although this increases the irradiation doses.

When the target ablation site is located too close to the coronary arteries, cryoablation appears to be a safe alternative. Even if cryoablation catheters are less compliant and are associated with a success rate lower than RF, the risk/benefit ratio may be in favor of this energy in this particular location especially if the coronary angiogram is not documented or CARTO-UNIVU™ is not available. Despite reports of coronary spasm during Cryo Maze procedures using an argon-based cryoablation system [14], Stavrakis et al. reported that none of the patients who underwent cryoablation within 5 mm of a CA had any anomaly on the angiography [8]. Aoyama et al. achieved the same results in canine models [15]. We had similar results with no CA injury, even in the absence of a security margin using 6 and 8 mm cryoablation catheter tips (Fig. 4). Cryoablation alone successfully eliminated AP conduction in 17 of 26 (65%) patients in the study by Stavrakis [8]. In our study, the success rate of cryoablation was not statistically different from the rates achieved with RFni and RFi (Table 4). Limiting RFni power may be another option to prevent coronary injury. Three patients with a CA in close proximity to the ablation site had limited RF energy application to 15 W. There was no recurrence in these patients and no CA injury.

## 6 Conclusion

Ablation of posteroseptal accessory pathways is challenging because of a significant risk of CA injury which is probably underestimated. Coronary angiography is mandatory before catheter ablation for PsAPs in children. Post-ablation angiography should also be strongly considered when using RF energy. Systematic coronary angiograms integrated into the CARTO-UNIVU™ system, the limitation of RF energy, or the switch to cryoablation, are possible strategies to limit the risk of CA injury. If the safety margin in insufficient or coronary angiogram not available, cryoablation seems to be the more rational strategy.

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