Coronary Artery Stenosis After Radiofrequency Catheter Ablation of Accessory Atrioventricular Pathways in Children With Ebstein’s Malformation

Harald Bertram, MD; Regina Bökenkamp, MD; Matthias Peuster, MD; Gerd Hausdorf, MD; Thomas Paul, MD

Background—Complications concerning the coronary arteries that are directly related to radiofrequency catheter ablation procedures have not been reported in children. Coronary artery lesions, however, have been demonstrated after the endocardial application of radiofrequency current in young animals.

Methods and Results—Two boys with Ebstein’s anomaly of the tricuspid valve developed clinically asymptomatic coronary artery stenosis after radiofrequency catheter ablation of right-sided accessory atrioventricular pathways with standard catheter technology.

Conclusions—The complication of coronary artery stenosis demonstrates a substantial risk after right atrial free wall radiofrequency current application in children. The risk of late coronary alterations should be considered when the use of catheter ablation procedures to young patients is proposed. (Circulation. 2001;103:538-543.)

Key Words: ablation ■ stenosis ■ pediatrics ■ Wolff-Parkinson-White syndrome ■ Ebstein’s malformation

The mid- or long-term effects of radiofrequency current (RFC) delivery to mature and growing myocardium have not been defined yet.1–3 In consideration of the proximity of the coronary arteries to the ablation sites of accessory pathways (APs), the coronary arteries might be at risk during ablation procedures.1 Obstruction of the right coronary artery (RCA) as a late sequelae after RFC application to the tricuspid valve annulus has been described in an animal model.4,5 It has been inferred that in humans, ablation procedures that target right free wall APs may damage the RCA.3

No permanent damage to the coronary arteries caused by RFC catheter ablation in pediatric patients has been reported in the literature. We report on 2 children, 4 and 6 years old at the time of catheter ablation, who subsequently developed coronary artery stenosis close to the endocardial RFC application sites.

Methods

Electrophysiological Study and Ablation Procedure

Venous access to the heart was achieved through the femoral vessels. A heparin bolus of 100 IE/kg body wt was administered at the beginning of the study, followed by 24 hours of continuous intravenous heparin (200 IE · kg body wt⁻¹ · d⁻¹) after the procedure. Two diagnostic quadripolar electrode catheters (5F to 6F, Josephson; CR Bard) were placed in the His bundle region and the right ventricle, respectively. Then 6F or 7F steerable mapping and ablation catheters (Dr Osypka GmbH and Medtronic CardioRhythm, respectively) equipped with an integrated thermistor or thermocouple at the 4-mm tip electrode were positioned under fluoroscopic control according to the ECG findings, which defined the location of the AP as reported previously.6,7 RFC was delivered with a radiofrequency generator (HAT 300; Dr Osypka GmbH; or Atakr; Medtronic CardioRhythm) in the unipolar mode against a plate electrode under the back of the patients with simultaneous registration of temperature, power output (796 to 1340 J), and impedance (80 to 120Ω). Surface ECG and bipolar intracardiac electrograms were displayed continuously. Standard RFC applications (target temperature 70°C, power output limited to 30 W) were continued for 30 seconds. The total number of RFC applications were 5 in the first patient (maximum temperature 74°C) and 21 in the second patient during 3 ablation sessions, respectively. In the latter patient, 6 RFC impulses with a maximum temperature of 50°C and a total energy of 8771 J were applied in the area of the subsequent coronary artery stenosis. The cumulative energy delivered per fiber was 2434 J in the first and 18 822 J in the second patient, respectively. The overall duration of the ablation sessions including the preceding electrophysiological study (EPS) in these patients varied between 125 and 210 minutes, and the fluoroscopy time varied between 12 and 47 minutes. Both patients received acetylsalicylic acid (ASA) at 2 to 3 mg · kg⁻¹ · d⁻¹ for the next 6 months after catheter ablation.

Case Reports

Patient 1

The first patient was a boy with Ebstein’s anomaly of the tricuspid valve, moderate tricuspid regurgitation, and Wolff-Parkinson-White (WPW) syndrome who experienced recurrent episodes of symptomatic paroxysmal supraventricular tachycardia (SVT) despite medical treatment (propafenone/sotalol) since his second year of life. At the age of 6 years (body weight 22 kg), an EPS was performed. Two
Figure 1. A, Surface ECG after ablation of first AP displaying sinus rhythm without preexcitation. B, Recording of surface ECG (top: leads I, III, aVF, V₁, and V₆) and bipolar intracardiac electrograms (bottom: HRA, mapping and ablation catheter [clipped]; CS 1-2, CS 3-4, CS 5-6, CS 7-8, CS 9-10, distal to proximal recordings from decapolar coronary sinus catheter; RV 1-2, right ventricular apex) during successful ablation of posterior AP in patient 1. Marked ST-segment elevation in leads III and aVF during RFC application is evident. Tachycardia is terminated by conduction block in AP. C, Surface ECG in sinus rhythm 10 minutes after energy delivery (B). Repolarization abnormalities were less evident and finally resolved 5 minutes later.
right-sided APs were identified in the posterior and posteroseptal locations, respectively. The posteroseptal AP was successfully ablated with the fourth energy pulse. The subsequent surface ECG did not exhibit repolarization abnormalities (Figure 1A). RFC application for interruption of the posterior pathway resulted in tachycardia termination after 10 seconds, accompanied by distinct ST-segment elevation predominantly in surface ECG leads II, III, and aVF (Figure 1B). Energy delivery was continued for a total of 15 seconds. The repolarization abnormalities subsequently normalized within 20 minutes (Figure 1C). A baseline angiogram of the RCA was not performed. After nitroglycerin instillation into the ostium of the RCA, the subsequent coronary angiogram was considered normal. No additional RFC pulses were applied despite still inducible SVT, and medical therapy was continued. There was no elevation of myocardial enzymes after the ablation procedure. During follow-up, ECGs predominantly showed sinus rhythm with right bundle-branch block pattern without repolarization abnormalities suspicious for myocardial ischemia. Intermittent preexcitation, however, was present. Because of recurrent SVT episodes despite medical treatment, a second EPS was performed 20 months later. Endocardial mapping again revealed the identical right posterior location of the remaining AP. Simultaneously performed selective coronary angiograms clearly demonstrated a severe narrowing of the posterolateral branch of the RCA over a distance of 11 mm (Figure 2, top and bottom) in direct proximity to the mapping catheter (Figure 3, top and bottom). No further RFC applications were carried out. Fluorodeoxy-glucose (FDG)-PET of the heart revealed a homogeneous myocardial glucose uptake except for a small zone of markedly reduced metabolic activity inferobasal, representing a transmural scar (Figure 4). This area correlated with the coronary stenosis in the

**Figure 2.** Selective RCA angiography (top, sagittal view; bottom, lateral view) 20 months after RFC catheter ablation procedure in patient 1: long-distance stenosis of posterolateral branch (arrows).

**Figure 3.** RCA angiogram (top, sagittal view; bottom, lateral view) after endocardial mapping with identical localization of residual accessory pathway. Mapping catheter is displayed in direct projection on coronary artery stenosis (arrows).
RCA angiogram, displaying its functional evidence. More than 2 years later, the boy is asymptomatic concerning clinical signs of myocardial ischemia. He is currently free of SVT under antiarrhythmic medical therapy (5 mg/kg sotalol) and receives 100 mg/d ASA.

Patient 2
The second patient also had Ebstein’s malformation of the tricuspid valve with moderate tricuspid regurgitation, an atrial septal defect (ASD), and WPW syndrome. An aortopulmonary shunt had been inserted at 4 months of age. The child experienced recurrent paroxysmal SVT episodes since he was a newborn. Medical therapy consisted of 4 drugs, including amiodarone. During EPS at the age of 2.9 years, a right anterolateral AP was successfully ablated. The preexcitation pattern on the surface ECG disappeared, and ventriculoatrial dissociation was proved with right ventricular stimulation at 500 ms. However, symptomatic SVT reoccurred a few months later. A second EPS was carried out 13 months later (body weight 17.7 kg), combined with hemodynamic catheterization to evaluate interventional ASD closure. Selective coronary angiography demonstrated normal coronary arteries. A right posterolateral concealed AP was identified and successfully ablated. No repolarization abnormalities were noted during any of the ablation procedures or during follow-up. Interventional catheterization with closure of the ASD (CardioSEAL septal occluder) and coil occlusion of the stenotic aortopulmonary shunt was carried out 14 months after the last RFC application. Selective coronary angiography during this procedure documented stenosis in the marginal branch of the RCA over a distance of 12 mm (Figure 5, top and bottom). Functional relevance was again proved with FDG-PET, which disclosed a diminished coronary flow reserve of lateral portions of the posterior wall after adenosine administration (Figure 6). This area corresponded well with the myocardial regions supplied by the marginal branch of the RCA. At 30 months after the last ablation procedure, there still is no clinical evidence of myocardial ischemia. No further SVTs occurred during follow-up, and this patient also receives 50 mg/d ASA.

Discussion
Coronary Artery Affections After Catheter Ablation
No cases of direct damage to the coronary arteries in children undergoing ablation procedures have been published so far. Late evaluation of the coronary arteries in children after catheter ablation, however, has not been reported from any center.1

There have been several anecdotal reports on either acute6–15 or chronic16,17 coronary artery complications during RFC catheter ablation procedures in adults, almost exclusively confined to the left coronary artery. These complications have generally been considered as catheter-induced dissections of the left coronary artery6,8,9,11,16 or embolic events10–13 rather than direct physical thermic effects of the RFC application. Nevertheless, myocardial infarctions due to RFC-induced thrombotic occlusion of the marginal branch of the circumflex artery and a posterior right atrial coronary artery, respectively, have been described.14,17 In addition, chronic left main coronary artery occlusion in a young woman 2 years after RFC application in the left ventricle has been reported.16

Experimental Studies
Animal studies have contributed important findings to the risk of coronary artery involvement after RFC ablation. After the creation of lesions at the right atrial aspect of the tricuspid valve annulus in young pigs, a significant narrowing of the RCA lumen (25% and 40%, respectively) due to intimal thickening was found in 2 of 5 animals after 6 months.4 The hypothesis that RFC ablation procedures may damage the RCA has been confirmed in a subsequent experimental study with the same animal model.5 Right atrial lesions that extend to the adjacent right coronary artery and lead to coronary artery obstruction from increased fibrous tissue content in adventitia and media with additional intimal thickening were found in 3 of 8 animals after 12 months.4 The hypothesis that RFC ablation procedures may damage the RCA has been confirmed in a subsequent experimental study with the same animal model.5 Right atrial lesions that extend to the adjacent right coronary artery and lead to coronary artery obstruction from increased fibrous tissue content in adventitia and media with additional intimal thickening were found in 3 of 8 animals after 12 months. Narrowing of the coronary artery lumen could be documented by intracoronary ultrasound in all 3 animals during follow-up studies 6 and 9 months after RFC delivery, respectively, whereas angiogra-
RFC application on the coronary arteries did not show a significant difference in the mean endocardial lesion-to-coronary artery distance between affected and unaffected animals, but there was a tendency to a shorter distance between the endocardial ablation site and the RCA in hearts with coronary artery involvement. Multivariate analysis could not demonstrate an effect of energy delivery parameters on the resulting lesion volume.

Whether patients with Ebstein’s anomaly of the tricuspid valve are at an increased risk to develop coronary artery lesions after RFC application remains speculative. There are no major differences in the tricuspid annulus/coronary artery relationship between patients with Ebstein’s malformation and subjects with normal hearts. The wall of the atrialized right ventricle is known as thinned and fibrotic, but data concerning the thickness of the right atrial wall in pediatric patients with Ebstein’s disease have not been published.

In general, patients with Ebstein’s malformation and right free wall atrioventricular APs tend to undergo more difficult ablation procedures with the need for multiple energy applications and often require >1 ablation procedure to be cured of paroxysmal SVT. Multiple APs are common in these patients. Even at centers with much experience, primary failure rates of RFC ablation in patients with Ebstein’s disease reach 24%, combined with significant recurrence rates. The number of RFC applications as well as the cumulative energy applied to our 2 patients are well within the range reported for ablation procedures in patients with Ebstein’s disease.

**Time Course of Coronary Artery Stenosis After Catheter Ablation**

The development of coronary artery stenosis must be considered a late complication of RFC application. Early reevaluation failed to demonstrate coronary artery lesions in adult dogs histologically and in adult patients angiographically. The ST-segment elevation during RFC application in the first patient was initially considered as transient thermic irritability that caused coronary artery spasm, as has been reported previously. Beyond this, transient repolarization abnormalities that mimic myocardial ischemia often occur after the ablation of manifest APs. These latter findings are considered to be due to cardiac memory rather than to myocardial ischemia during ablation.

The unexpected formation of a long-segment coronary artery stenosis (Figures 2 and 5), however, emphasizes the need for late control studies at least 12 months after the ablation procedure. Selective coronary artery angiography ideally combined with intracoronary ultrasound should be performed in every patient with transient signs of myocardial ischemia during RFC application. A control angiography after 12 months should also be attempted in all children with Ebstein’s anomaly who undergo ablation of atrioventricular APs. Considering the results of the experimental studies, this recommendation may even be expanded to all children after the ablation of right free wall APs to provide more insight into the incidence of coronary artery stenosis after RFC catheter ablation in structurally normal hearts.

**Figure 5.** Top, Selective RCA angiogram with stenosis (length 12 mm) of marginal branch (arrows) 14 months after RFC ablation of right free wall AP in patient 2. Bottom, Detailed view to elucidate RCA stenosis (arrows).
In conclusion, there are substantial late tissue effects after catheter ablation with RFC in the young. The development of coronary artery stenosis in 2 children with Ebstein’s malformation demonstrates a potential risk of right atrial RFC applications in children. These findings are supported by the results of animal studies in structurally normal hearts. Long-term follow-up that includes reevaluation of the coronary arteries seems to be mandatory in children with Ebstein’s malformation who undergo right free wall RFC applications and in every patient with signs of myocardial ischemia during energy application.

References
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