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Long-term results of catheter ablation for ventricular tachycardia in arrhythmogenic right ventricular cardiomyopathy/dysplasia

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ABSTRACT

Aims: This study analyzed the arrhythmogenic substrates and mechanisms of ventricular tachycardia (VT), and long-term outcomes of catheter ablation in patients with arrhythmogenic right ventricular cardiomyopathy/dysplasia (ARVC/D).
Methods: Nine patients (1 female, 40 ± 17 years) with ARVC/D and sustained monomorphic VT (SMVT) exhibiting left bundle branch block morphology of the QRS complex were studied. The diagnosis of ARVC/D was confirmed by means of echocardiography, magnetic resonance imaging, and electroanatomical mapping in all patients.
Results: The patients underwent 10 ablation procedures. At the initial ablation, the mean VT rate was 196 ± 21 (170–240) bpm. In total, 17 VT types were observed. One VT type with left axis (+I, aVL), or right axis (+II, III, aVF) of the QRS complex was present in 3 and 1 patient, respectively. Two VT types of left and intermediate (+I, II, aVL) axis or of left and right axis of the QRS complex were observed in 3 and 2 patients, respectively. Multiple VT types with left axis QRS complex recurred in 1 patient. One VT displayed characteristics of focal arrhythmia, the mechanism of remaining VTs was clearly macroreentrant. The critical slow-conducting isthmus of the reentry circuit was located at the infero-lateral aspect of tricuspid annulus and was bounded by the annulus and baso-lateral wall scar in 7 VTs, the isthmus was located within the scars in the remaining VTs. During 52 ± 31 (12–93) month follow-up since the last ablation, 8 (89%) patients remained free from any VT recurrence without antiarrhythmic drug.
Conclusions: Patients with ARVC/D frequently presented with ≥ 1 SMVT type. The critical isthmus of reentry circuit was dominantly located close to the tricuspid annulus. Long-term outcome of extensive endocardial ablation was favorable with isolated VT recurrences in one patient.

SOUHRN

Cíl: Tato studie analyzovala arytmogenní substráty a mechanismy komorové tachykardie (KT) a dlouhodobé výsledky katetrizační ablace u pacientů s arytmogenní kardiomyopatií/dysplazií pravé komory (ARVC/D).
Metodika: Bylo hodnoceno devět pacientů (jedna žena, 40 ± 17 let) s ARVC/D a setrvalou monomorfní KT (SMKT) s komplexem QRS tvaru levého Tawarova raménka. Diagnóza ARVC/D byla u všech pacientů potvrzena echokardiograficky, magnetickou rezonancí a elektroanatomickým mapováním.
Výsledky: Pacienti podstoupili deset ablačních výkonů. Při první ablaci byla průměrná frekvence KT 196 ± 21 (170–240)/min. Celkem bylo zaznamenáno 17 typů KT. Jeden typ KT s osou komplexu QRS doleva (+I, aVL) nebo doprava (+II, III, aVF) byl přítomen u tří, respektive u jednoho pacienta. Dva typy KT s levou a intermediární (+I, II, aVL) osou nebo s levou a pravou osou komplexu QRS byly přítomny u tří, respektive dvou pacientů. Tři jiné typy KT s osou komplexu QRS doleva recidivovaly u jednoho pacienta. Jedna KT jevila charakteristiky fokální arytmie, mechanismus ostatních KT byl jasně reentry. Kritický můstek pomalého vedení reentry okruhu byl lokalizován u inferolaterálního aspektu trikuspidálního prstence a byl ohraničen trikuspidálním prstencem a bazolaterální jizvou u sedmi KT, u ostatních KT byl kritický můstek lokalizován uvnitř jizvy. Během sledování 52 ± 31 (12–93) měsíců od poslední ablace zůstávalo osm (89 %) pacientů bez recidivy KT bez antiarytmik.

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Klíčová slova:
ARVC/D
Katetrizační ablace
Komorová tachykardie
Výsledky

Závěr: Pacienti s ARVC/D měli často ≥ 1 typ SMKT. Kritický můstek reentry okruhu se nacházel převážně blízko trikuspidálního prstence. Dlouhodobé výsledky extenzivní endokardiální ablace byly příznivé s izolovanými recidivami KT u jednoho pacienta.

Introduction

Arrhythmogenic right ventricular cardiomyopathy/dysplasia (ARVC/D) represents a genetically determined hereditable disorder afflicting predominantly right ventricle (RV). Patchy replacement of myocytes by adipose and fibrous tissue may result in ventricular tachycardia (VT)/fibrillation, sudden cardiac death, and RV failure [1,2]. Despite implantation of automatic cardioverter-defibrillator (ICD) as the therapeutic mainstay to prevent sudden cardiac death, catheter ablation is often necessary to reduce arrhythmic burden and improve quality of life [3–5]. Although ARVC/D is a progressive disease, progression of structural changes may be relatively slow or step-like in some patients [6], and successful ablation may eliminate arrhythmia recurrences for years. Epicardial ablation approach may become necessary in some patients [5,7,8]; however, meticulous endocardial RV mapping and extensive ablation including the peri-tricuspid rim can be successful in a substantial proportion of patients.

This retrospective study of catheter ablation of VT in ARVC/D aimed at investigating the arrhythmogenic substrates, VT mechanisms, and ablation outcomes in one center over eight years.

Methods

The study included 9 patients (1 female) aged 40 ± 17 (17–71) years with ARVC/D and sustained monomorphic VT (SMVT). These patients represented 8% of 110 patients undergoing catheter ablation of SMVT associated with structural heart disease in one center between January 2004 and August 2011. All patients fulfilled the major arrhythmic criterion of ARVC/D in terms of SMVT with left bundle branch block (LBBB) morphology and superior axis of the QRS complex (Table 1). ARVC/D was also confirmed by means of echocardiography and magnetic resonance imaging (MRI) in all patients. Presence of echocardiographic, MRI, and additional electrocardiographic criteria indicative of ARVC/D according to the revised task force proposal [9] is shown in Table 2. Left ventricular ejection fraction was in normal range in all except one patient, and coronary angiography was negative in all patients in whom it was performed. Two patients (#1 and 9) presented with the family history of sudden cardiac death in young male relatives. Four (44%) patients underwent ablation after the first documented VT episode, 3 (33%) patients were referred to catheter ablation following VT recurrences, and 2 (22%) patients due to frequent recurrent VT despite chronic use of amiodarone with discharges of already implanted ICD. Individual baseline characteristics are shown in Table 1.

For the electrophysiological study, a 4-pole catheter (Biosense Webster, Diamond Bar, CA, USA) was introduced into the RV for pacing, a 10-pole catheter (Daig, St. Jude, Minnetonka, MN, USA) was positioned in the coronary sinus, and a mapping/ablation catheter (NaviStar ThermoCool, Biosense Webster) was inserted via 8 F long sheath (Mullins fixed curve, Daig, St. Jude) in the RV. Bipolar endocardial electrograms were filtered at a band-

Table 1 – Baseline characteristics.

N. pt	G	Age	CA	LVEF	VT 1st	VT rec	VT hist	Symptoms					DCC	ICD	AAD
								P	H	Fa	PS	S			
1	M	59	0	60	+			+	+		+		+		0
2	M	46	0	60		+	21	+	+		+	+		+	Amio
3	M	31	–	55		+	70	+		+					0
4	M	71	0	60		+	60		+		+	+	+		0
5	M	22	0	30		+	18	+			+			+	Amio
6	M	17	–	60	+			+		+					0
						+								+	0
7	M	58	0	65	+				+		+		+		0
8	F	29	–	65		+	120	+		+					Prop
9	M	34	0	55	+				+			+	+		0

AAD – antiarrhythmic drug; Age – shown in years; Amio – amiodarone; CA – coronary angiography; DCC – external electrical cardioversion with direct current; F – female; Fa – fatigue; G – gender; H – hypotension; ICD – discharges from already implanted automatic cardioverter-defibrillator; LVEF – left ventricular ejection fraction in %; M – male; P – palpitations; Prop – propafenon; PS – presyncope; pt – patient; S – syncope; VT 1st – first episode of ventricular tachycardia; VT hist – history of ventricular tachycardia recurrences in months; VT rec – recurrent ventricular tachycardia; 0 – negative finding; – – not performed.

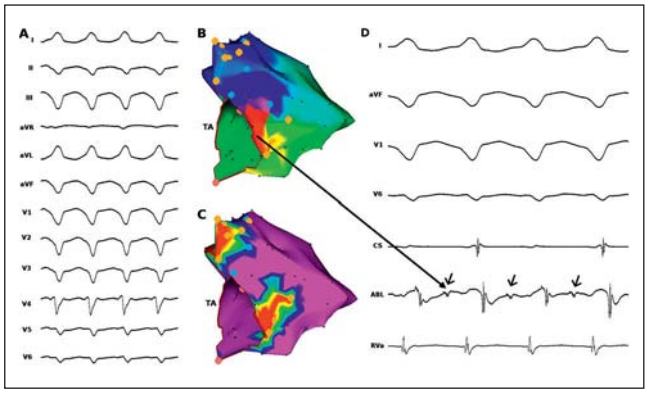

Fig. 1 – Electroanatomical mapping of the right ventricle (roughly right oblique projection) during ongoing ventricular tachycardia with LBBB morphology and left axis deviation (+I, aVL) on standard 12 lead ECG (50 mm/s) (A) (patient #1). Activation mapping (B) indicates the location of critical slow-conducting isthmus close to infero-lateral tricuspid annulus, where the latest activation at the superior entrance into the isthmus (coded in purple) meets the earliest activation at the inferior exit from the isthmus (coded in red), and where isolated mid-diastolic potentials shown by arrows are recorded during the tachycardia by the mapping/ablation catheter (ABL) on panel D. The tachycardia impulse propagates over a double reentry circuit simultaneously around the tricuspid annulus and around the baso-lateral scar that is coded in red on the voltage map (C). Atrial potentials recorded by catheter in the coronary sinus (CS) are dissociated from the ventricular potentials.
RVa – recording from the right ventricular apex; TA – tricuspid annulus. ECG speed on Panel D 100 mm/s.

-pass setting of 30–500 Hz and displayed on Cardiolab System (Prucka Engineering, Sugar Land, TX, USA).

The study protocol was commenced with standard programmed and incremental ventricular pacing with the aim to induce all VT types (all VT QRS complex morphologies and rates) that were subsequently targeted by mapping and ablation. Hemodynamically tolerated VTs were preferentially mapped selectively during the ongoing arrhythmia using electroanatomical activation mapping (CARTO system, Biosense Webster) (Fig. 1). Simultaneously, detailed bipolar voltage electroanatomical RV reconstruction was accomplished using the voltage criteria < 0.5 mV to identify scar (low vol-

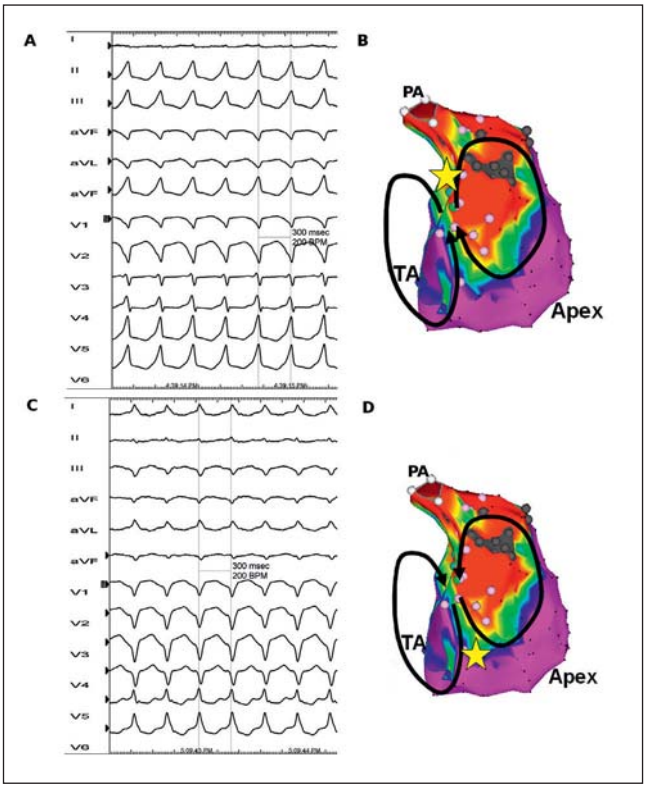

Fig. 2 – The figure shows an example of a pair of ventricular tachycardia that was approached by substrate mapping/ablation (patient #7). The pair of ventricular tachycardia exhibits the same rate, and alternating right-axis QRS complex (+II, III, aVF) (A) or left-axis QRS complex (+I, aVL) (C). These tachycardias resulted from rotation over the same double-loop reentry circuit alternately in the opposite directions as schematically depicted by black arrows on Panels B, D. The critical isthmus of slow conduction was located between an extensive right ventricular baso-lateral scar (coded in red on the voltage electroanatomical map in Panels B and D) and the tricuspid annulus (TA). During the tachycardia with right or left axis QRS complex, respectively, the electric impulse exited the critical isthmus either superiorly (B) or inferiorly (D) (exit sites are marked by yellow asterisks).
PA – pulmonary annulus; TA – tricuspid annulus. Normal myocardium displaying voltage > 1.5 mV on the electroanatomical voltage maps was coded in purple color.

Table 2 – Echocardiographic, MRI, and ECG criteria of ARVC/D.

N. pt	2D ECHO criteria		MRI criteria		Depolarization abnormalities		Repolarization abnormalities	
	Major	Minor	Major	Minor	Major	Minor	Major	Minor
1		+		+			+	
2		+		+			+	
3		+		+				
4	+		+		+		+	
5	+		+		+		+	
6	+		+		+		+	
7	+		+		+		+	
8		+		+	+		+	
9	+		+					+

ARVC/D – arrhythmogenic right ventricular cardiomyopathy/dysplasia; ECHO – echocardiographic; MRI – magnetic resonance imaging; pt – patient.

tage area of fatty/fibrous tissue) and >1.5 mV to identify normal myocardium, so that all possible anatomical conduction barriers were delineated. In addition, the sites of diastolic potentials were tagged, and entrainment mapping was subsequently applied to confirm the location of critical slow-conducting isthmus within the conduction barriers. In case of hemodynamically unstable VT, electroanatomical RV reconstruction during sinus rhythm was completed to identify gross RV anatomy and possible anatomical conduction barriers (Fig. 2). Late potentials were further recorded and tagged. Then pace-mapping was performed to identify the central part of critical isthmus of slow conduction (pace-mapping with QRS complex matching the VT QRS complex in all 12 leads and long stimulus-QRS complex interval), and the exit from critical isthmus (pace-mapping with QRS complex matching the VT QRS complex in all 12 leads and zero stimulus-QRS complex interval). Finally, if the patient partially tolerated VT, following identification of the VT critical isthmus by mapping during sinus rhythm, the VT was induced for a short time to prove that the late potentials recorded during sinus rhythm corresponded to the mid-diastolic potentials during ongoing VT, and that the VT could be terminated by ablation at that site (Fig. 3). Irrespective of the primary mapping approach (selective or anatomically guided), ablation was always extended across the whole critical isthmus(mi) and all late potentials were eliminated. At the end of the study, a complete standard protocol of programmed ventricular pacing was repeated to prove noninducibility ideally of any VT. Radiofrequency energy was applied with a Stockert generator (Biosense Webster). We used irrigation of 30 ml/min (heparinized 0.9% saline) and temperature and power limits of 42 °C and 50 W.

Results

Ablation procedure characteristics and immediate results

The nine patients underwent a total of 10 ablation procedures. Procedure, fluoroscopy, and radiofrequency delivery times were 199 ± 57 (120–300) minutes, 10 ± 6 (4–21) minutes, and 32 ± 26 (11–94) minutes, respectively. All nine initial ablation procedures were completed with noninducibility of any VT. In one patient (#6), other types of SMVT recurred one year later and the patient underwent a repeat ablation for multiple SMVTs. This procedure eliminated several SMVT types, while one type of fast SMVT remained inducible despite repeat VT termination with radiofrequency application (details in Table 3).

Electrophysiological findings

Morphologies of ventricular tachycardia

In total, 14 VT types of LBBB morphology were observed during the first ablation procedure (Table 3). At the initial ablation, the mean VT rate was 196 ± 21 (170–240) bpm. One VT type of left axis QRS complex (+I, aVL) was present in 3 patients, and one VT type of right axis QRS complex (+II, III, aVF) was found in 1 patient. Two VT types of left and intermediate (+I, II, aVL) axis QRS complex were observed in 3 patients, and two VT types of left and right axis QRS complex were present in another 2 patients (Table 3) (Fig. 4 and Fig. 5). When 2 VT types were observed spontaneously or were induced by ventricular pacing, they usually repre-

Table 3 – Electrophysiological findings and long-term outcomes.

N. pt	VT count	VT rate	VT QRS axis	VT isthmus	Anatomical barriers	NI	ICD	FU	VT rec	AAD
1	2	190	+I, aVL +I, II, aVL	TA Lat	TA-Lat scar	+	–	93	0	0
2	1	200	+I, aVL	RV Inf-Lat	Within Lat scar	+	++	93	0	0
3	2	190	+I, aVL +I, II, aVL	TA Inf-Lat	TA-Lat scar	+	+	81	0	0
4	1	195	+I, aVL	TA Inf-Lat	TA-Lat scar	+	–	61	0	0
5	2	170	+I, aVL +II, III, aVF	TA Inf-Lat	TA-Lat scar	+	++	46	0	0
6	1 Multi	170 205 220 255	+II, III, aVF +I, aVL +aVR, aVL	RV Ant RV Inf	Ant scar Within Inf-Lat-Apic scar	+ –	+ ++	 26	 0	0 Sot
7	2	200	+I, aVL +II, III, aVF	RV Lat	Within Lat scar	+	+	38	0	0
8	1	210	+I, aVL	RV Inf	Lat-Apic scar	+	–	19	0	0
9	2	240	+I, aVL +I, II, aVL	TA Inf-Lat	TA-Lat scar	+	+	12	0	0

Ant – high anterior; Ant-Lat – anterolateral; Apic – inferoapical scar; BL scar – baso-lateral lateral scar extending individually superiorly or inferiorly; FU – post-ablation follow-up in months; ICD – automatic cardioverter-defibrillator; Inf-Lat – inferolateral; Lat – lateral; Multi – multiple VT types; NI – noninducibility; pt – patient; RV – right ventricle; Sot – sotalol; TA – tricuspid annulus; VT rate in beats per minute; – – not implanted; + – implanted after ablation; ++ – implanted before ablation.

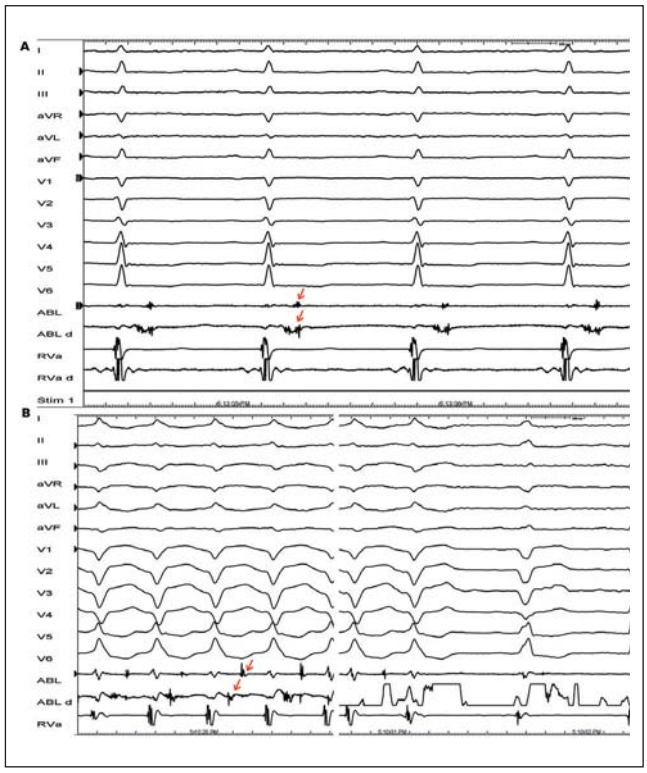

Fig. 3 – The figure shows an example of late potentials (red arrows) recorded by the proximal and distal bipole of the ablation catheter (ABL, ABL d) during sinus rhythm at the critical slow-conducting isthmus located between right ventricular baso-lateral scar and tricuspid annulus (patient #7) (A). During induced ventricular tachycardia, mid-diastolic potentials (red arrows) were recorded at the same site, and subsequent ablation terminated the tachycardia (B).
ECG speed – 100 mm/s. RVa d – bipolar recording from the right ventricular apex.

sented a pair of VTs of the same rate rotating alternately in both directions around one reentry circuit that was eliminated by ablation of one common critical slow-conducting isthmus (Fig. 2). At repeat ablation, several SMVT types displaying positive QRS complex in leads I, aVL or in leads aVR, aVL were induced in one patient (Table 3) (Fig. 6).

Sites of origin of ventricular tachycardia

At first ablation, VT types with left axis of the QRS complex (n = 8) originated from an inferior exit of the critical isthmus close to TA (n = 5) (Fig. 1), from an inferior exit of the critical isthmus traversing through the RV baso-lateral scar (n = 2), and from the critical isthmus between basal infero-lateral scar and infero-apical scar (n = 1). VT types with right axis of the QRS complex (n = 3) originated from a superior exit of the critical isthmus close to TA (n = 1) (Fig. 2), or from a superior exit of the critical isthmus traversing through the RV baso-lateral scar (n = 1). In addition, 1 incessant irregular VT with right axis deviation of the QRS complex originated from a localized source within the high anterior scar in one patient (patient #6) (Fig. 4). Finally, VT types with intermediate QRS complex axis (n = 3) arose from a superior exit of the critical isthmus close to TA when the baso-lateral scar constituting the other conduction barrier was located rather inferiorly (n = 1), or from a mid-level exit from the critical isthmus traversing through the baso-lateral scar (n = 2) (Fig. 5).

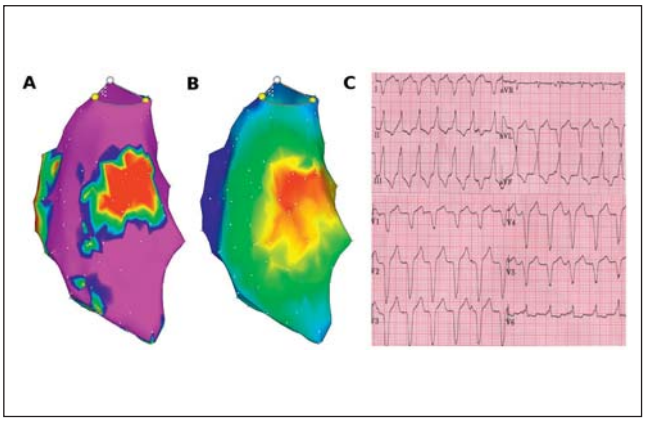

Fig. 4 – The figure shows an example of a "focal" ventricular tachycardia. Patient #6 initially presented with one type of incessant irregular VT displaying right axis of the QRS complex (C) that originated from the high anterior right ventricular scar, exhibited centrifugal endocardial activation of the rest of right ventricle (A, B), and was eliminated by focal ablation at the site of earliest activation marked in red on activation map (B). Panel A shows voltage map in the same projection, where red color coded areas with voltage < 0.5 mV (scars). Location of high anterior scar on the voltage map (C) spatially correlated with the site of earliest activation on the activation map (B).

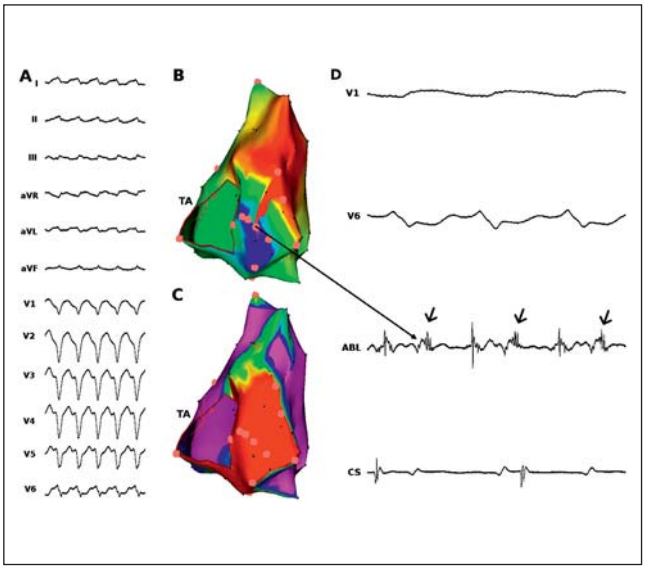

Fig. 5 – Electroanatomical map of the right ventricle (in roughly right oblique projection) during ongoing ventricular tachycardia with intermediate axis (+I, II, aVL) of the QRS complex on standard 12 lead ECG (A) (patient #3). Activation mapping (B) indicates location of the critical slow-conducting isthmus close to lateral aspect of the tricuspid annulus, where the latest activation at the site of inferior entrance into the isthmus (coded in purple) meets the earliest activation (coded in red) at the site of exit from the isthmus (traversing obliquely through the scar) at the medium-level basal lateral right ventricular wall. At the site of critical isthmus, isolated mid-diastolic potentials shown by arrows are recorded by mapping/ablation catheter (ABL) during the tachycardia (D). Voltage mapping (C) shows an extensive baso-lateral scar coded in red, while normal myocardium exhibiting voltage > 1.5 mV is coded in purple color. Atrial potentials recorded by catheter in the coronary sinus (CS) are dissociated from the ventricular potentials.
TA – tricuspid annulus. ECG speed on Panel D 200 mm/s.

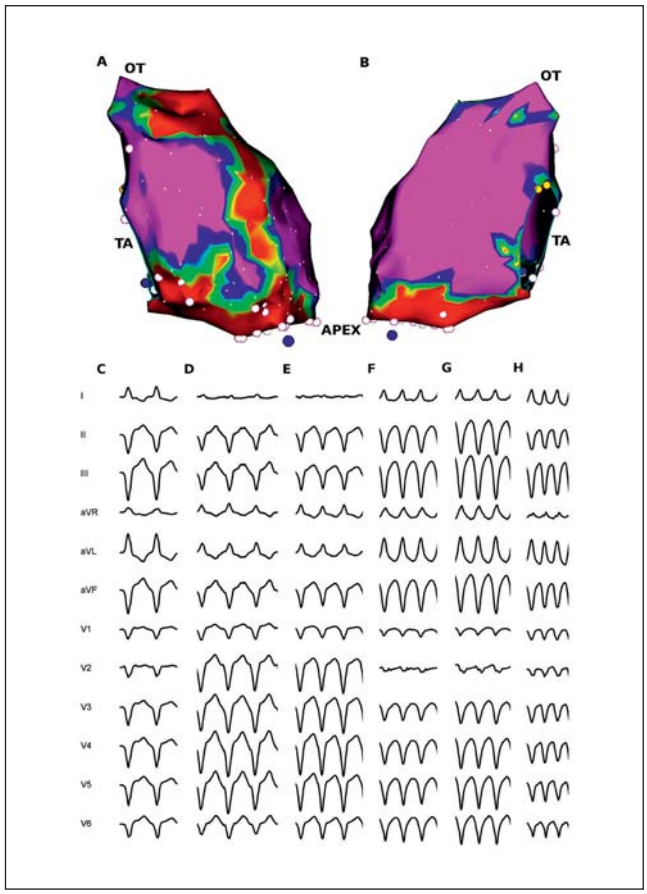

Fig. 6 – Electroanatomical voltage map of the right ventricle shows in roughly right oblique projection an extensive scar stretching from inferior across lateral to anterior right ventricular wall (voltage < 0.5 mV coded in red) (A) (patient #6). Septum exhibited normal myocardium with voltage > 1.5 mV coded in purple (B). Multiple types of ventricular tachycardia were targeted at inferior and infero-apical wall, where white dots mark the sites of late potentials during sinus rhythm. Basically four types of VT morphologies were observed, some of which occurred with various rates. Type 1 VT (rate 120 bpm) (C), type 2 VT (rate 230–260 bpm) (F, G), and type 3 VT (330 bpm) were targeted at the basal inferior wall, type 4 VT (rate 160–210 bpm) (D, E) arose from the infero-apical segment. These tachycardias newly developed despite achieving noninducibility of any ventricular tachyarrhythmia at the end of prior procedure after ablation of ventricular tachycardia originating at the anterior wall (see Fig. 4).
OT – outflow tract; TA – tricuspid annulus.

Critical isthmi of reentry circuits

The critical isthmi of slow conduction were found between the TA and baso-lateral scar in 5 patients. They were formed by relatively narrow slow conducting channels abutting to the TA laterally (n = 1), inferolaterally (n = 3), and inferiorly (n = 1) depending on the more superior or inferior location/extension of the baso-lateral scar (Fig. 1 and Fig. 2). In other 3 patients, the critical slow-conducting isthmus traversed through the baso-lateral scar (n = 2) (Fig. 5). Finally, the critical isthmus between the basal infero-lateral scar and infero-apical scar was observed in 1 patient (1 VT type in patient #8). Extensive infero-apical scar formed the source of multiple VT types displaying basically two axes of the QRS complex with different rates in patient #6 at repeat ablation (Fig. 6).

Long-term outcome

During the long-term follow-up of 52 ± 31 (12–93) months since the last ablation, 6 patients received ICD (4 patients after the successful ablation), while 3 patients declined ICD implantation. Eight (89%) patients with single ablation remained free from any VT recurrence without class I or III antiarrhythmic drug. SMVT recurred in only 1 patient, who continues medication with sotalol (patient #6) and who experienced two isolated SMVT episodes during 26-month follow-up after the last ablation. These VT recurrences were terminated by overdrive pacing from ICD (Table 3).

Discussion

This study retrospectively analyzed long-term results of radiofrequency catheter ablation of SMVT in patients with ARVC/D. The major findings of the study are as follows: 1) Patients with ARVC/D-related SMVT represented 11% of all patients with structural heart disease, who underwent VT ablation. 2) More than half of the patients presented with ≥ 1 SMVT type, mostly a pair of SMVT alternately rotating around one reentry circuit in both directions. 3) The critical isthmus of slow conduction was dominantly located along lateral-to-inferior aspect of the TA bounded by the TA on one side and by the baso-lateral scar on the other side. 4) Meticulous RV mapping including the peri-tricuspid rim identified the SMVT source in all the patients. 5) Long-term outcome of extensive endocardial ablation was favorable with isolated VT recurrences in one patient.

ARVC/D is a relatively rare condition with estimated prevalence ranging between 0.05% and 0.02% of the total population [2,10]. In this study, patients with ARVC/D-related SMVT represented 11% of all patients with VT ablation due to major structural heart disease, which was more than expected based on the ARVC/D prevalence. One possible explanation of this discrepancy may lie in the early indication to catheter ablation of ARVC/D-related SMVT, often after the first documented SMVT episode, as it was considered a reasonable initial therapeutic step because of patient's age, probability of further VT recurrences, and potential need for AAD therapy. On the contrary, catheter ablation of VT in the setting of prior myocardial infarction or dilated cardiomyopathy was usually resorted to after ICD had been implanted and all conventional therapeutic options including amiodarone to suppress frequent VT recurrences had failed. If ablation in patients with other major structural heart diseases had been implemented earlier, the proportion of patients with ARVC/D-related SMVT would have been lower.

Prior studies employing endocardial VT ablation reported partly diverse results in relatively small ARVC/D populations ranging from 11 to 24 patients [3,4,11–13]. The worst outcomes were presented when a majority of ablation procedures were performed conventionally (79%) leading to only 23% success rate in achieving immediate elimination of all inducible VTs, and very low 25% VT recurrence-free survival after the 14-month follow-up period [12]. On the other hand, and similarly to our results,

using electroanatomical or non-contact 3-dimensional mapping, most of the induced VTs were eliminated by ablation and following repeat ablation, nearly 90% of the patients remained free from VT long-term, while the remaining patients experienced only rare VT recurrences [3,13].

In the prior studies, the critical slow-conducting isthmi were frequently found very close to the TA and were bounded by the TA and RV baso-lateral scar. Other possible boundaries of the critical isthmi were formed by pulmonary valve and outflow tract scar or by two separate free-wall scars [3,4,11]. In our patients, the critical isthmi located at the para-tricuspid rim stretched from lateral to inferior aspect of the TA depending individually on the extent and/or location of baso-lateral RV scar. They were often relatively narrow and abutted the TA very closely so that distinct atrial potentials were typically recorded at the successful ablation site. It is likely that without meticulous mapping and ablation of the TA itself some of these VT sources might have been missed or VT would have recurred due to inadequate isthmus transsection.

In one patient, focal source of VT was observed. This VT arose from inside the low-voltage area (scar), and its mechanism has remained speculative, as the VT presented as incessant, slightly irregular arrhythmia interrupted by periods of sinus rhythm, suggesting rather ectopic origin. RV free-wall localized VT sources in ARVC/D patients have been previously described to be associated with a relatively low 50% success rate of endocardial ablation [11]. Limited efficacy of ablation of these "focal" VTs may stem from the fact that they may represent only endocardial breakthrough with endocardial centrifugal activation pattern, while the entire reentrant circuit is located epicardially [14]. Epicardial substrate was suspected in our patient with "focal" VT in whom later multiple different SMVTs recurred despite noninducibility of any VT at the end of the initial ablation. Besides the ambiguity of the primary "focal" VT mechanism, presence of progressive endo-epicardial substrate was supported by the course of repeat ablation when one VT type remained inducible despite repeated delayed termination during radiofrequency energy delivery.

Findings from autopsy examinations and endocardial--epicardial electroanatomical mapping studies showed that arrhythmogenic substrate in ARVC/D may be more extensive epicardially than endocardially [15,16]. Recent studies further proposed that more extensive epicardial voltage abnormalities may be identified by endocardial electroanatomical mapping [17], and that delayed epicardial activation from combined endocardial and epicardial mapping may suggest VT circuits contained entirely within the epicardium [18]. In addition, there has been increasing evidence that some of the VTs can be eliminated only by epicardial ablation approach [5,8,16,19]. Epicardial ablation successfully eliminated VT in 77% of the patients with prior failed endocardial ablation, and additional 15% of the patients had only single VT recurrence [19]. Further, combined endocardial and epicardial catheter ablation employed as the primary strategy lead to the VT noninducibility in all patients with subsequent 91% VT-free long-term outcome [16]. One study randomizing 49 ARVC/D patients to primary combined endo-epicardial substrate-based ablation versus sole endocardial ablation proved superiority of the former approach by showing long-term freedom from ventricular arrhythmias in 85% of the patients, whereas only 52% of the patients with endocardial ablation remained free from further VT recurrences ($p = 0.029$) [8]. Finally, long-term outcomes in 87 ARVC/D patients from 80 different centers showed better VT-free survival at 5 years when epicardial ablation was involved compared to endocardial ablation alone [5].

In our patients, favorable outcomes of pure endocardial ablation may be partly related to relatively extensive and aggressive ablation employed from the initial stages of our experience. The results were achieved in ARVC/D patients exhibiting similar profile in baseline characteristic as in above mentioned prior studies including preponderance of males and mean age. Noninducibility of any VT was achieved in all patients at the first ablation procedure. Only one patient with suspect early progression of the RV structural changes, who required repeat ablation for newly developed distinct SMVT types, experienced two isolated SMVT recurrences during long-term follow--up (see also above). These findings indicate possible slow progression of the dysplastic changes, or long periods of entire remission in some patients or at some stages of the disease [6].

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