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Electrocardiographic Pattern as a Guide for Management and Radiofrequency Ablation of Idiopathic Ventricular Tachycardia

Hildegard Tanner Thomas Wolber Nicola Schwick Juerg Fuhrer
Etienne Delacretaz

Swiss Cardiovascular Center Bern, University Hospital, Bern, Switzerland

Key Words
Ventricular tachycardia · Catheter ablation

Abstract
Background: Idiopathic ventricular tachycardia (VT) often originates from the right ventricular outflow tract (RVOT), but foci deep to the endocardium, in the epicardium, or in the left ventricle are not uncommon. Although these extra-RVOT foci can be targeted with ablation, risks involved are higher and success rates lower. Simple electrocardiographic (ECG) criteria allowing (1) discrimination of RVOT foci from extra-RVOT foci and (2) assessment of the chance of success of a right heart ablation procedure are desirable. ***Methods:*** Twenty-five consecutive patients referred for radiofrequency (RF) ablation of idiopathic VT or severely symptomatic idiopathic ventricular premature contractions were included. Localization of VT origin and success rates of VT ablation in the RVOT were analyzed according to the ECG pattern. ***Results:*** The analysis of the R wave in V2 was the strongest single predictor of whether the VT had an RVOT or an extra-RVOT origin. An R wave amplitude ≤30% of the QRS amplitude designated the VT focus in the RVOT with positive and negative predictive values of 95 and 100%, respectively. Analysis of R wave duration in V2 had similar predictive values, whereas the R/S transition zone in precordial leads had slightly lower predictive values. Seventeen of 20 arrhythmias (85%) with an R wave amplitude ≤30% of the QRS amplitude in V2 could be successfully abolished by an exclusively right heart procedure. ***Conclusions:*** The analysis of ECG pattern makes it possible to guide the management of patients with idiopathic VT in predicting the arrhythmias that can be safely targeted with RF ablation from the RVOT with high success rates.

Introduction

Radiofrequency (RF) catheter ablation is a curative therapy for idiopathic ventricular tachycardias (VT) or repetitive premature ventricular contractions in patients with structurally normal hearts [1–3]. A number of these arrhythmias originate from the right ventricular outflow tract (RVOT) and can be ablated with high success rates and a very low risk [1–3]. However, some arrhythmias have their origin deep to the RVOT endocardium, epicardially, or in the left ventricular outflow tract and are more difficult to target with RF ablation [2, 4, 5]. Although left ventricular endocardial foci and some of the epicardial foci can be ablated successfully [2, 4, 6, 7], the risks of a procedure targeting the left ventricular outflow tract from

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Etienne Delacretaz, MD, FESC
Swiss Cardiovascular Center Bern
University Hospital
CH–3010 Bern (Switzerland)
Tel. +41 31 632 21 11, Fax +41 31 632 42 99, E-Mail etienne.delacretaz@insel.ch

the left ventricular chamber or an epicardial site from the aortic sinus of Valsalva are higher than the risks of an ablation in the RVOT [8]. Furthermore, the success rate of ablation of left-sided foci is lower than for arrhythmias originating in the RVOT [7, 9]. Predicting the site of VT origin is useful for the management of patients with idiopathic VT, since conservative therapy may be preferred in patients with VT originating from extra-RVOT sites.

Several electrocardiographic (ECG) algorithms have been developed to classify idiopathic VT according to the site of origin, allowing localization of the VT origin in up to six different outflow tract sites using up to seven analysis steps [9, 10]. However, there is a need for simple ECG criteria indicating whether the VT focus can be targeted from the right ventricle or not.

The purpose of this study was to determine ECG criteria allowing (1) discrimination of RVOT foci from extra-RVOT foci and (2) assessment of the chance of success of RF ablation from the RVOT.

Methods

Patient Population

Consecutive patients referred to the Swiss Cardiovascular Center Bern for RF ablation of focal VT or frequent ventricular premature contractions were included. All patients had ECG documentation of their arrhythmia. Echocardiography, stress test and/or coronary angiography and/or magnetic resonance imaging had been performed prior to the referral to rule out structural heart disease in all except 3 patients.

ECG Measurements

Twelve-lead electrocardiograms of the clinical arrhythmia were available for all patients. The QRS morphology of the first beat of VT or the premature ventricular contraction were analyzed focusing on the following characteristics: (1) the site of R wave transition in the precordial leads; (2) the magnitude of R and S waves in leads V1, V2, and V3, and (3) the duration of R and S waves in lead V2. The following definitions of ECG waveform morphologies were used: the precordial transition zone was defined as the earliest precordial lead in which the R wave amplitude exceeded that of the S wave. The R wave duration index was calculated for lead V2 by dividing the R wave duration by the QRS complex duration. The R wave amplitude index was calculated for leads V1–V3 as the value of the R wave amplitude divided by the QRS complex amplitude.

Electrophysiology Study

Electrophysiologic tests were performed after discontinuation of all antiarrhythmic agents except in 2 patients who were taking amiodarone. After written informed consent had been obtained, a 5-french quadripolar or hexapolar (with 2 proximal poles in the vena cava inferior to be used as indifferent electrode for unipolar pacing) electrode catheter was inserted into the right femoral vein and advanced to the apex of the right ventricle. A 7- or 8-french mapping and ablation catheter (Celsius DSa or Navi-Star, Cordis Webster) was introduced into the femoral vein and advanced into the right ventricle, or in case of a left VT using a retrograde approach through the right femoral artery. An initial bolus of 5,000 IU of heparin was administered intravenously. Twelve-lead surface ECG and intracardiac recordings were recorded at paper speeds of 25, 100 and 200 mm/s or stored digitally (CardioLabo, Prucka Engineering). Mapping was performed either guided by fluoroscopy or by an electroanatomical navigational system (CARTO, Biosense Webster). If clinical VT was inducible or if ventricular premature complexes were spontaneously present or inducible (with ventricular stimulation and/or intravenous isoproterenol), activation mapping was performed by sampling of ventricular endocardial electrograms, looking for the site of the earliest local activation. The interval between the downstroke of the unipolar electrogram and the onset of the QRS complex was determined. If ectopic activity could not be induced, pace mapping was performed, aiming to identify the site where pacing exactly reproduced QRS morphology during VT.

RF Ablation

RF ablation was performed using a 4-mm-tip standard RF catheter. In 7 cases a saline-irrigated-tip catheter was used to achieve a deeper lesion. RF energy was applied in the temperature-controlled mode and continued for a maximum of 2 min. RF current application was discontinued if measured impedance increased, a pop occurred, the catheter changed position or the patient complained about pain despite sedation with fentanyl and midazolam. The effect of RF current application – short runs of VT and VT termination – was observed. Acute procedural success was defined as abolition of spontaneous and inducible (programmed stimulation and isoproterenol) VT. In patients without spontaneous or inducible VT or premature ventricular contraction and who underwent ablation guided by pace mapping, success was defined by complete disappearance of ectopic activity shown by 24-hour ambulatory ECG recordings and stress tests more than 2 months after the procedure.

Extra-RVOT Foci

VT focus was considered to be localized at an extra-RVOT site (endocardial in left ventricle, deep to RVOT endocardium or epicardial) when (1) the longest endocardial activation to QRS onset times were 20 ms or less and applications of RF current at the earliest activation time in the RVOT failed to terminate VT, or (2) the endocardial activation to QRS onset times was >15 ms longer in the coronary sinus, aortic cusps, or left ventricular endocardium than in the RVOT, or (3) RF ablation from the left ventricular endocardium was successful.

Follow-Up

Patients were followed-up by phone calls. They were asked about symptoms, further need for antiarrhythmic agents, and complications after hospital discharge. Twenty-four-hour ambulatory ECG recordings and/or stress tests more than 2 months after RF ablation were obtained in patients with ventricular premature contractions or nonsustained VT prior to RF ablation.

Statistical Analysis

Data were expressed as means (SD) unless otherwise specified. The Mann-Whitney test or unpaired Student's t test was used for comparison of quantitative data. Fisher's exact test was used for comparison of qualitative data. A p value <0.05 was considered statistically significant.

Table 1. ECG characteristics of VT originating from the RVOT and from extra-RVOT sites (deep to RVOT endocardium, left ventricular, epicardial)

	Focus RVOT (n = 19)	Focus remote from RVOT (n = 6)	p value
QRS duration, ms	127 (13)	141 (12)	0.02
R wave amplitude, mV			
V1	1 (1)	6 (4)	<0.001
V2	2 (2)	8 (4)	<0.001
V3	5 (3)	17 (9)	<0.001
R wave amplitude index, %			
V1	6 (6)	71 (38)	<0.001
V2	9 (8)	58 (27)	<0.001
V3	28 (25)	78 (22)	<0.001
R wave duration in V2, ms	28 (13)	104 (3)	<0.001
R wave duration index in V2, %	22 (11)	73 (18)	<0.001
R wave in V1 <1 mV, n[a]	13 (70%)	0 (0%)	0.07

R wave amplitude index was calculated for leads V1–V3 by dividing the R wave amplitude by the QRS complex amplitude. R wave duration index was calculated for lead V2 as the ratio of the R wave duration divided by the QRS complex duration.

[a] Figures in parentheses represent standard deviations unless otherwise indicated.

Results

Patients Characteristics

The study comprised 25 consecutive patients [12 women, 13 men, mean age 50 years (SD12), range 21–72] who were referred for RF ablation of idiopathic VT or frequent ventricular premature contractions. The symptoms consisted of syncope in 3 patients and palpitations in 22 patients. Eighteen patients had VT, and 7 patients had frequent ventricular premature contractions. Nine patients had exercise-related symptoms, none had a history of cardiac arrest. Twenty-three patients had unsuccessful treatment or were intolerant to treatment with a range 1–4 antiarrhythmic agents, including β-blocking agents (n = 22), calcium antagonists (n = 10), sotalol (n = 4), amiodarone (n = 2), and flecainide or propafenone (n = 2). Two patients had no antiarrhythmic therapy; one of them had sustained VT, which was severely symptomatic, and was directly referred for RF ablation, and the other one declined antiarrhythmic therapy. Of these 25 patients, 22 had no structural heart disease, 1 patient had hypertensive heart disease, 1 had one-vessel coronary artery disease with normal left ventricular ejection fraction, and 1 patient had dilated cardiomyopathy.

Mapping and RF Ablation

Twenty patients had spontaneous or inducible ventricular ectopy allowing activation mapping. Despite discontinuation of antiarrhythmic therapy ventricular ectopy was not inducible at baseline and during isoprotenerol infusion in 5 patients. Therefore, pace mapping was used to identify the site of origin of the tachycardia. In 18 patients RF ablation was performed using a 4-mm-tip standard RF catheter. In 7 cases a saline-cooled-tip catheter was used. A mean of 4 (SD5) RF pulses (range 1–27) per patient was applied. Local response – termination of VT or short-lived bursting focal activity – was observed in 18 patients. RF ablation was successful in 18 of 25 patients (72%). In patients with successful RF ablation the interval from the earliest endocardial activation time to QRS onset was longer than in patients with unsuccessful ablation, 32 ms (SD5) versus 15 ms (SD6), respectively (p = 0.03). The success rate was similar whether an electroanatomic navigational system or conventional fluoroscopy was used (p = nonsignificant). Three of 5 patients in whom pace mapping was the main mapping method were successfully ablated. The success rate was higher in the group with exercise-related VT (100%) than in the group without exercise-related VT (60%, p = 0.04). The reason of failure was judged to be a deep or epicardial focus in 5 patients and insufficient premature ventricular contractions with unsuccessful ablation guided by pace mapping in 2 patients. There were no complications.

Extra-RVOT Foci

In 3 patients, mapping of left ventricle, aortic cusps, and/or coronary sinus was performed. Earliest local activation sites were found in the left ventricular endocar-

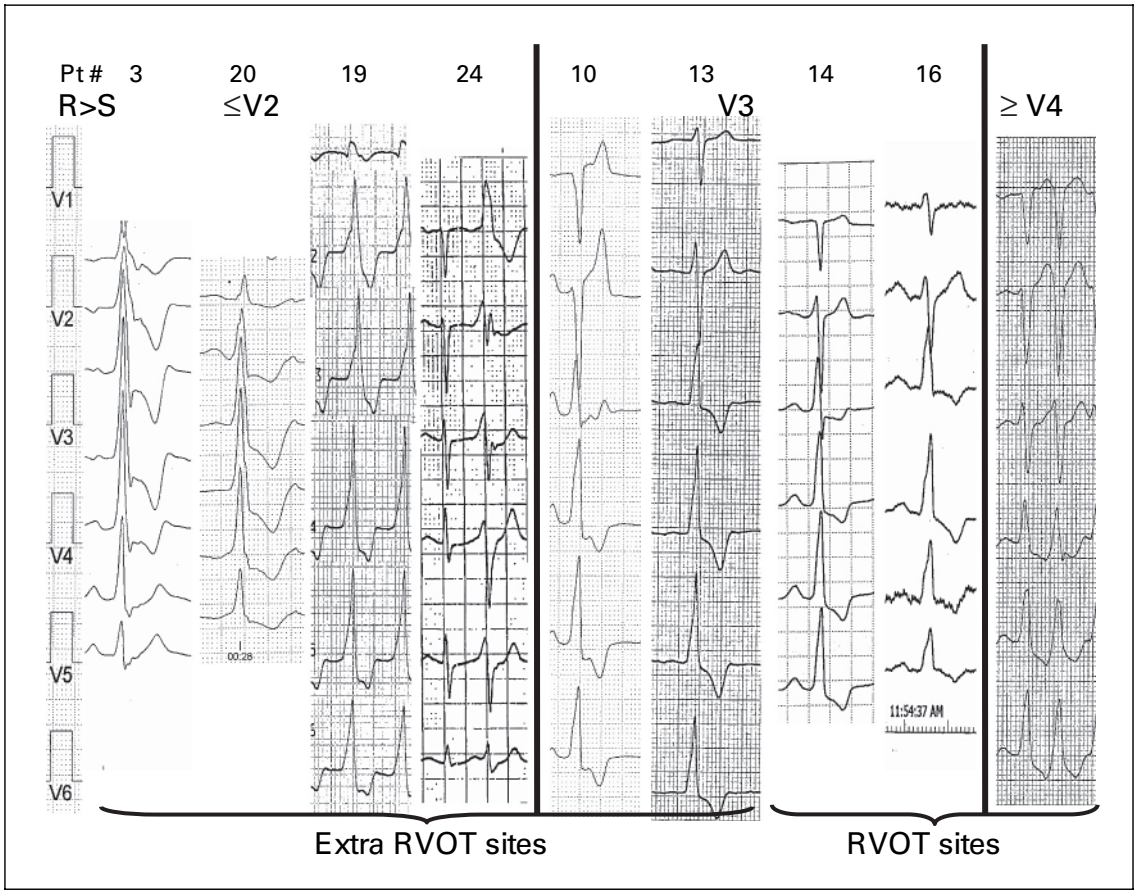

Fig. 1. Localization of VT focus in relation to precordial transition zone in precordial leads. VT with precordial transition zone at V2 or earlier all had an extra-RVOT origin. In half of the patients with precordial transition zone at V3 the origin was localized in the RVOT. When precordial transition zone transition was at V4 or later, RF ablation from the RVOT had high rates of success.

dium in 2 patients and in the anterior portion of the coronary sinus in 1 patient. Only 1 of the 3 RF ablation attempts was successful. In the other 2 patients, the longest endocardial activation to QRS onset times found during extensive mapping of RVOT was 20 ms or less and RF ablation applications at the earliest activation time in the RVOT failed to terminate VT.

ECG Characteristics of VT

The QRS duration of VT with an extra-RVOT origin was slightly longer compared to that of VT with an RVOT origin (table 1). The incidence of inferior axis during VT was similar for patients with RVOT and extra-RVOT foci (19/19 and 5/6, respectively). The VT with an origin remote from the RVOT showed significantly greater R wave amplitudes and greater R wave amplitude indexes in lead V1–V3 than the VT with an origin in the RVOT (fig. 1, 2, table 1). Furthermore, the R wave duration and R wave duration indexes in V2 were shorter in patients with RVOT foci than in patients with extra-RVOT foci (fig. 2, table 1). The VTs with an origin in the RVOT showed an rS (n = 11) or QS (n = 8) pattern in lead V1, and five of six VTs with an extra-RVOT origin showed an rS pattern in lead V1 (fig. 1). VTs with an origin in the RVOT had a median precordial transitional zone at lead V4 (range V3–V5), whereas all six VTs with failed ablation had precordial transitional zones at lead V3 or earlier (fig. 1).

Predictive Value of ECG Parameters

The analysis of the R wave in V2 was the strongest single predictor of whether the VT had an RVOT focus or an extra-RVOT focus (fig. 2): an R wave amplitude index of 30% or lower indicated an RVOT focus with a positive

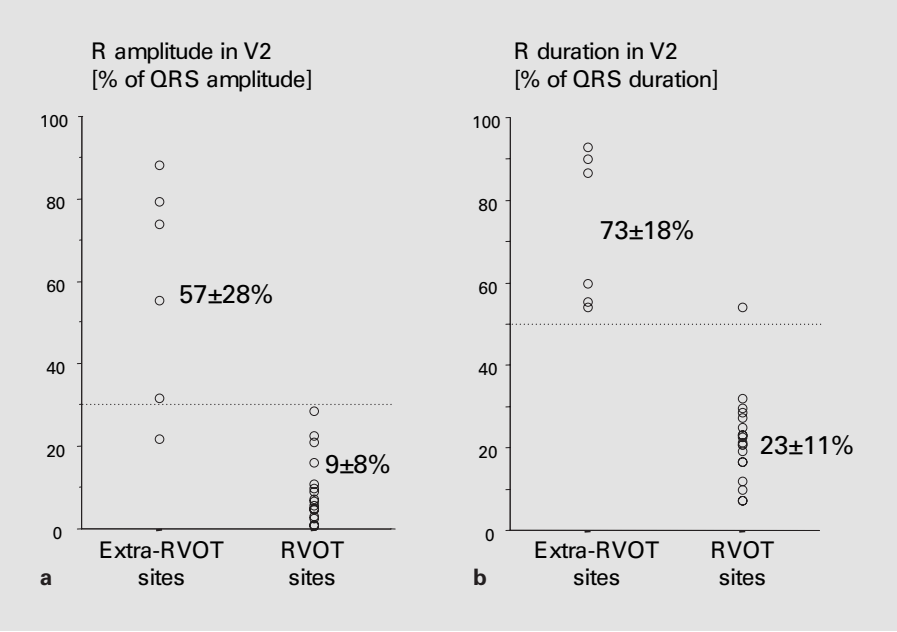

Fig. 2. Plot of the indexes of R wave duration (**a**) and R/S amplitude (**b**) in patients with repetitive monomorphic ventricular tachycardia originating from the right ventricular outflow tract and from extra-RVOT sites (deep to RVOT endocardium, left ventricular, or epicardial).

predictive value of 95% and a negative predictive value of 100%. An R wave duration index of 50% or lower indicated an RVOT focus with a positive predictive value of 100% and a negative predictive value of 86%. Seventeen of 20 arrhythmias (85%) with R wave amplitude ≤ 30% of the QRS amplitude in V2 could be successfully abolished by an exclusively right heart procedure.

A precordial transitional zone at or after lead V4 during VT predicted the localization of the VT origin in the RVOT (positive predictive value 100%; negative predictive value 75%) and successful ablation from the RVOT (positive predictive value 88%; negative predictive value 75%). Acute success rates of an ablation from the RVOT were high (88%, 15 of 17) for the arrhythmias with a precordial transition zone at V4 or later, and intermediate (50%, 2 of 4) in patients with a precordial transition zone at V3 ($p < 0.01$). When R/S transition was at V2 or earlier (n = 4), RF ablation from the right side was not possible.

Follow-Up

Antiarrhythmic therapy was discontinued in all 18 patients with successful RF ablation. Of these 18 patients, 17 were free of recurrence after a mean follow-up of 12 months (SD5) (range 1–56 months). Symptomatic ventricular premature contractions recurred in a patient in whom the ablation was guided by pace mapping because of very few premature ventricular contractions. All other patients were free of symptoms and most of them had confirmation of success with long-term ECG and/or stress test. Thus, long-term success was achieved in 17 patients (68%). There were no early or late complications.

Discussion

In patients with structurally normal hearts, idiopathic VT and ventricular premature contractions often originate from the RVOT [1–3], but foci deep to the RVOT endocardium, epicardial, or in the left ventricle are not uncommon [2, 4, 5]. Although some left ventricular outflow tract and epicardial foci can be successfully targeted from the left ventricular chamber or from the aortic sinus of Valsalva [2, 4, 6, 7], left-sided procedures targeting extra-RVOT foci have a higher risk and a lower success rate than RF ablation in the RVOT [7–9]. Indeed, it may be reasonable to limit RF ablation through the aortic cusps or in the left ventricle to treatment of the most severely symptomatic patients. Thus, when facing a patient with idiopathic arrhythmias from the outflow tract, one question is whether RF ablation from the right ventricle can be successful. Stepwise algorithms have been developed to localize VT focus [9, 10]. A seven-step algorithm was shown to allow classification of VT origin in six different outflow tract areas with positive and negative predictive values of 88 and 96%, respectively [9]. However, these algorithms are not likely to be used in clinical

practice. There is a need for simple criteria to guide management of patients with symptomatic focal VT or repetitive ventricular premature contractions.

The present analysis included 25 patients with symptomatic focal idiopathic VT or ventricular premature beats. The overall acute and long-term success of RF ablation was 72 and 68%, respectively. The analysis of the R wave in V2 was the strongest predictor of whether the VT had an RVOT focus or an extra-RVOT focus (fig. 2): an R wave amplitude index of 30% or lower indicated an RVOT origin with a positive predictive value of 95% and a negative predictive value of 100%. Seventeen of 20 arrhythmias (85%) with R wave amplitude index $\leq 30\%$ in V2 could be successfully ablated with an exclusively right heart procedure. Two ablation failures were related to the paucity of spontaneous and inducible ventricular premature contractions and were probably not due to the impossibility to reach the focus from the RVOT. Indeed, Wen et al. [11] found that use of pace mapping alone for the ablation site selection was a predictor of tachycardia recurrence. An R wave duration index of 50% or lower indicated an RVOT focus with a positive predictive value of 100% and a negative predictive value of 86%. However, precise measurement of R and S wave durations may be difficult and inaccurate measurement may alter the sensibility and specificity of this parameter, especially for R and QRS durations close to the cutoff value. Thus, the R wave amplitude index is the best single parameter to localize VT origin and predict the success of RF ablation from the RVOT.

Localization of VT focus in relation to the precordial transition zone was also analyzed. All the VT with transition in V4 or later had an R wave amplitude index $\leq 30\%$ in V2. Furthermore, all the VT with a precordial transition zone at V2 or earlier had an origin in the left ventricle. Therefore, to simplify ECG analysis, analysis of the R/S transition zone may be assessed first. The precordial transition zone in V4 or later indicates an RVOT focus. A precordial transition zone at V2 or earlier indicates an extra-RVOT site. When the precordial transition zone is at V3, the R wave amplitude index can be calculated to further specify the origin of VT. This two-step analysis has a positive predictive value of 95% and a negative predictive value of 100%.

Other authors have studied R wave progression in precordial leads in relation with the site of successful RF ablation. A precordial R wave transition at or before lead V2 was shown to be consistent with a left ventricular origin of VT [4]. Kautzner et al. [12] and Krebs et al. [5] demonstrated that outflow tract VT with precordial transition zones at lead V3 could not be ablated from the RVOT. However, we and other authors have found that some of the VT with the transition zone at lead V3 could be ablated from the RVOT (fig. 1) [13]. Indeed, it appears that the presence of a transition zone in V3 does not allow localization of VT origin with certainty. The presence of an R wave in V1 has also been used to discriminate right-sided foci from extra-RVOT foci [13]. However, previous studies have demonstrated that the precordial R wave transition zone occurred earlier as the focus of VT moved from the anterior inferior septum to the posterior superior septum of the RVOT [14, 15]. RVOT VT often have a significant R wave in V1, particularly for posteroseptal foci, which may mimic left aortic cusp VT [10]. In our series, 11 of 19 patients with VT origin in the RVOT had a significant R wave in V1.

Finally, in 7 patients with successful RF application to the right or left aortic sinus of Valsalva, the percentage dividing the longer R wave duration in lead V1 or V2 by the QRS complex duration was significantly higher than in 8 patients with RVOT VT [6]. Moreover, the ratio of R/S wave amplitude in V1 was significantly higher in those patients with an extra-RVOT focus than in the group with an RVOT focus. Determination of cutoff values for both variables made it possible to identify 6 of 7 patients who had VT ablated with RF application in the aortic cusps. However, larger series showed that less than half of the VT with an extra-RVOT origin cannot be ablated in the aortic cusps [9], and this study did not include any other extra-RVOT VT foci.

Clinical Implications

We propose a simple ECG analysis to guide the management of patients with idiopathic outflow tract arrhythmias in predicting the chance of success of RF ablation from the RVOT. A precordial transition zone at V4 or later identifies VT with an RVOT origin which can be targeted from the RVOT with high success rates. VT with a precordial transition zone in V3 may have either RVOT or extra-RVOT foci. Ablation in the RVOT can be successful if the R wave amplitude in V2 is $\leq 30\%$ of the QRS amplitude. In contrast, if the R wave amplitude in V2 is $>30\%$ of the QRS or if the precordial transition zone is at V2 or earlier, the focus may be deep to the endocardium, epicardial, or in left ventricular endocardium. Some of these VT can be successfully targeted with RF application through the (left or right) aortic cusps or in the left ventricular cavity, but the procedural risks are higher, and RF ablation should only be performed in severely symptomatic patients despite drug therapy. Knowledge of

this information may help to inform the patients about the success rate and potential complications of RF ablation and guide the decision of whether or not to proceed with an invasive procedure. Importantly, an accurate positioning of precordial leads is warranted to allow a correct interpretation of the R/S waves. For example, placement of an electrode too superiorly or not sufficiently laterally can minimize the R wave amplitude.

Limitations of the Study

(1) Positive and negative predictive values are approximate since they rely on the analysis of small groups. Furthermore, 4 of the 6 extra-RVOT foci had a monophasic R in V1 or V2, clearly consistent with an origin in the left ventricle, whereas a minority of extra-RVOT foci had an RS pattern in V2, a pattern intuitively more difficult to classify as consistent with RVOT versus extra-RVOT focus. Inclusion of more extra-RVOT foci with RS pattern in V2 might increase the risk of misclassification and decrease predictive values.

(2) Failure to successfully treat VT with RF application in the RVOT does not allow precise localization of the VT origin. In the present study, mapping or ablation in the left ventricular outflow tract and the aortic sinus of Valsalva was only performed in 3 of the 6 patients with extra-RVOT VT origin, because of potential risks of damage of coronary vessels, and concern over producing atrioventricular block. However, local activation in the RVOT was extensively mapped during VT/ectopy in all patients, and RF current application at the earliest local activation site remained without effect. Moreover, short endocardial activation to QRS onset times in RVOT strongly suggests that the VT focus was remote from the RVOT.

In conclusion, RF ablation is a curative therapy of idiopathic VT. Although idiopathic VT often originates from the RVOT, foci deep to the RVOT endocardium, epicardial, or in the left ventricular outflow tract are not uncommon. The analysis of the ECG pattern can discriminate between RVOT and extra-RVOT foci and guide the management of patients with idiopathic VT in predicting the arrhythmias that can be safely targeted with RF ablation from the RVOT with high success rates.

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