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The ECG in Right Ventricular Cardiomyopathy/Dysplasia. How Can the ECG Assist in Understanding the Pathological and Functional Changes of the Heart in This Disease?

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Introduction

The ECG provides important diagnostic information in patients suspected of right ventricular cardiomyopathy/dysplasia. The clinician needs to be aware of the ECG abnormalities in ARVC/D to ascertain the likelihood of patients having this disease. Several reviews of the ECG findings in ARVC/D have been published.^{1, 2}

The ECG changes in ARVC/D reflect the pathophysiology of ARVC/D that is characterized by progressive replacement of myocardial tissue in the free wall of the right ventricle by fibrous and fatty tissue. Normally the free wall of the right ventricle is the last part of the heart to undergo depolarization.³ If there is selective damage to the right ventricular free wall musculature there may be fragmentation and selective slowing and prolongation of the end of the QRS complex and this can be seen in the anterior precordial leads. The delay in depolarization may be extremely prolonged and may be visible as reproducible low frequency, low amplitude waves that extend beyond the QRS complex and before the T wave. These are known as postexcitation or epsilon waves.⁴ They are of low amplitude, and are usually visible only on the ECG leads overlying the right ventricle.

The diagnose of ARVC/D is based on a comprehensive evaluation of clinical, imaging, and ECG findings from the Task Force Criteria.⁵ Table 1 shows ECG parameters for the diagnosis of ARVC/D.

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Anterior Precordial T Wave Inversion

T wave inversion is often a manifestation of myocardial injury. For example, in patients with an anterior myocardial infarction, T wave inversion is a common ECG finding. Likewise, this is an ECG feature in patients with ARVC/D who have right ventricular free wall musculature replaced by fibrous-fatty tissue.⁶

Data from the NIH Registry of ARVC/D showed that the mean age of diagnosis of ARVC/D was 38 ± 14 years; there was a slight majority of males. In this registry cohort of newly diagnosed patients with ARVC/D, T wave inversion beyond V_1 was present in 56% of newly diagnosed patients. (Table 2) T wave inversion was limited to V_1 and V_2 in 6%, to V_1 , V_2 and V_3 in 16%, and extended beyond V_3 in 31%. In addition T wave inversion was not found in V_2 and V_3 but in V_4 , V_5 and V_6 in 3%. In normal individuals age 19–45, T wave inversion in V_1 , V_2 and V_3 is present in less than 3% of apparently healthy subjects.⁷ Thus this ECG finding is quite specific and relatively sensitive for the diagnosis. (Figure 1) This pattern of T wave inversion in $V_1 - V_3$ or beyond is frequently recorded in normal individuals less than age 14 and has been termed “a juvenile pattern” but this pattern is infrequent in the age group in which ARVC/D usually presents.

The extent of the precordial T wave inversion provides an indication of the extent of right ventricular involvement and/or enlargement. In the first detailed clinical profile of this disease⁶, T wave inversion in $V_1 - V_4$ was found in 86% (19 of 22 patients) in contrast to an incidence of 31% of T wave inversion in $V_1 - V_3$ of newly diagnosed patients in the above noted registry. The patients with a high incidence of T wave inversion in $V_1 - V_4$ had a more advanced stage of the disease since they were all referred to a tertiary care center because of ventricular tachycardia that was refractory to antiarrhythmic drugs. Nava et al. found that there was a direct correlation between the extent of T wave negativity in the precordial leads and right ventricular enlargement ($r=0.89$; $p<0.01$)⁸ Jadou et al noted that T wave inversion in $V_1 - V_3$ was observed in 37/74 (50%) of individuals with ARVC/D at time of initial diagnosis and this progressed to (65%) of patients over 9.5 ± 3.25 years.⁹

Delayed Activation of the Right Ventricle

It has long been recognized that there can be delayed repolarization of the right ventricle due to fibrous - fatty replacement of the cardiac chamber. In 1994 localized prolongation of the QRS complex >110 msec in $V_1 - V_3$ was included as a minor Task Force Criteria. The frequency of this finding has been reported to range from 24% (23 of 95 ECGs) in the NIH registry to 97 % reported by Peters et al.¹⁰ Again, the difference in the incidence of these findings are likely related to the extent of right ventricular structural and functional abnormality.

In recognition of the fact that QRS prolongation selectively involves the right ventricle in this disease, it should primarily affect the terminal portion of the QRS complex. Nasir et al observed that the terminal part of the QRS, defined as the time from the nadir of the S wave to the isoelectric line, was prolonged to > 55 msec. in $V_1 - V_3$ in 95% of patients with ARVC/D, in 7% of patients with RVOT tachycardia and in 2% of normal controls.¹¹ A

more recent publication from the same center reported that 91% of patients with ARVC/D had a prolonged S wave duration.¹²

Selective prolongation of the S wave duration in $V_1 - V_3$ has been verified by Cox et al. who reported this finding in 71% (30 of 42 patients).¹³ This was defined as the longest value measured from the nadir of the S wave to the end of all depolarization deflections including epsilon waves and was called the terminal activation delay (TAD). Once again the incidence appears to be less in newly diagnosed patients. It was observed in 34% (32 of 95 patients) with ARVC/D in the NIH registry. Reports of the duration of the QRS or S wave has the inherent problem of error of measurement error of these parameters from the standard 12 lead electrocardiogram. Cox et al. reported that individual measurements varied 2.9 ± 3.5 msec. with a range of 0–15 msec.

The epsilon wave may be defined as a reproducible low amplitude deflection on the ECG recording occurring between the end of the QRS complex and the onset of the T wave. This was well described by Fontaine et al. in 1978.⁴

Fontaine et al recognized that this was a delayed potential that resulted from slow conduction in localized areas of the right ventricle. It can be seen best in leads $V_1 - V_3$ since these leads are in close proximity to the right ventricle. When present in the 12 lead ECG it is invariably seen on the signal averaged electrocardiogram as a late potential. Nevertheless the signal averaged electrocardiogram may show late potentials that are not of sufficient amplitude to be visible on the 12 lead electrocardiogram. The presence of the epsilon wave also seems to reflect the extent of right ventricular involvement. It was observed in only one of 95 ECGs in the NIH registry. In patients with recurrent ventricular tachycardia reported in the original clinical description of ARVC/D these ventricular post excitation waves were present on the resting ECG in 7 of 22 patients and was recorded in 13 of 16 patients who had signal averaged electrocardiograms.⁶

The Electrocardiogram as an Aid to Differentiate Idiopathic VT (RVOT Tachycardia) from ARVC/D

It is important to differentiate individuals with RVOT (idiopathic) ventricular tachycardia from those who have ARVC/D since patients with RVOT tachycardia have an excellent prognosis and arrhythmic death is extremely rare. In contrast, ARVC/D is a progressive disease with frequent recurrence of ventricular tachycardias including the possibility of arrhythmic death. ECG findings that help to differentiate RVOT tachycardia from ARVC/D are shown in Table 3. The QRS morphology can assist in the differential diagnosis.

The ECG abnormalities described as frequently present in ARVC/D are uncommon in patients with RVOT tachycardia.^{14,15,16} This includes T wave inversion in V_1, V_2, V_3 and beyond or evidence of a prolonged terminal portion of the QRS complex (S wave duration of >55 msec) as well as epsilon waves and late potentials. T wave inversion in V_1, V_2 , and V_3 was seen in 36% of 17 patients with ARVC/D and 6% of patients with RVOT tachycardia.¹⁶ In a recent study, Cox et al. reported T wave inversion in V_1, V_2 , and V_3 in 28 of 42 (67% of patients with ARVC/D) but in none (0 of 27) patients with RVOT

tachycardia.¹³ Therefore the standard ECG is a valuable tool to assist in this differential diagnosis.

Patients with RVOT tachycardia invariably will have QRS complex of the ventricular ectopy that is of left bundle branch block morphology that is positive in the inferior leads 2, 3 and AVF and negative in AVL. Patients with ARVC/D may also have this morphology. However, if the ventricular ectopy has a left bundle branch block morphology with a superior QRS axis, this enhances the suspicion that the patient has this condition.

The importance of utilizing the morphology as well as the QRS axis of PVCs or ventricular tachycardia suggests that the physician should try to identify the morphology and the QRS axis from the Holter recording. Although one of the Task Force Criteria is that of the presence of ventricular arrhythmias by Holter monitor of > 1,000 per 24 hour, the recognition that the ventricular arrhythmias are of right bundle branch block rather than left bundle branch block morphology should decrease the suspicion of the presence of right ventricular cardiomyopathy/dysplasia.

The 12 lead electrocardiogram can also provide information to determine whether the left bundle branch block morphology of the ventricular tachycardia may be due to right ventricular outflow tachycardia or ARVC/D. A QRS duration > 120 msec in lead I has a sensitivity of 100%, specificity of 46%, positive predictive value of 61%, and negative predictive value of 100% for ARVC/D.¹⁷ The reason for this difference is undoubtedly related to the fact that the rate of depolarization of the right ventricle is slowed in patients with ARVC/D due to fibrous fatty tissue whereas the right ventricular structure and function is normal in patients with ARVC/D with resulting rapid ventricular depolarization.

The Signal Averaged ECG (SAECG) as an Aid in the Diagnosis of ARVC/D

A positive signal averaged electrocardiogram is another minor Task Force Criteria for this diagnosis. Recording of SAECG involves the use of special ECG equipment to markedly increase the amplitude of the QRS complex in order to accurately measure the duration of the QRS complex as well as to observe and measure the small electrical potentials that may occur after the end of the QRS complex.

For the 40 Hz high pass filter, the normal value for filtered QRS duration is 114 msec, the normal value of low amplitude signal duration below 40 uV (LAS 40) is 38 msec and the root – mean square voltage in the last 40 msec of the QRS (RMS 401) should be 20 uV.¹⁸ It has become common practice to classify the signal averaged ECG as positive if 2 of the 3 parameters are abnormal, although this categorization is not based on evidence.¹⁸ The presence of abnormal signal averaged ECG may provide information with regard to the differential diagnosis of ARVC/D versus RVOT tachycardia since the incidence of a positive signal averaged ECG is only a few percent in patients with RVOT tachycardia and is in the range of 50–60% or greater in patients with ARVC/D. (Table 1). Late potentials correlate with the severity of the disease but there are conflicting reports as to whether there is a correlation between the presence of late potentials to predict inducibility to ventricular tachycardia in patients with sustained VT.^{19,20,21}

The ECG to Aid in the Diagnosis of ARVC/D in Family Members

The penetrance of ARVC/D is variable; therefore the expression of the electrical phenomenon would be expected to have a lower incidence and be less severe than in the probands. This was observed by Hamid et al. who suggested that the diagnosis of ARVC/D in family members may be present without their having to fulfill the Task Force Criteria established for the probands.²² One major Task Force Criteria in addition to an established diagnosis of ARVC/D in a family member has been proposed as a diagnostic criteria for family members. A modification of the Task Force Criteria suggested by Hamid et al. is a PVC frequency of >200 PVCs per 24 hours rather than 1,000 PVCs for probands. This is based on the observation that the frequency of PVCs in a normal individual < 40 years of age is generally less than 200 PVCs per 24 hours and is frequently < 50 PVCs per 24 hours in individuals below the age of 20. A positive signal averaged ECG is also a useful criteria to suspect the diagnosis of ARVC/D in family members.

Summary

The electrical manifestations of right ventricular dysplasia are important to aid in the diagnosis of ARVC/D and also in the differential diagnosis of ARVC/D versus RVOT tachycardia. The findings are based on the pathophysiology of right ventricular free wall replacement of musculature by fibrous and fatty tissue causing abnormal repolarization as well as slow and delayed conduction.

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Figure 1.
An ECG from a patient with ARVC/D. The T waves are inverted in $V_1 - V_5$. The PVC recorded in leads AVR, AVL, AVF and lead II shows that this PVC is of LBBB configuration and has a superior QRS axis

Table 1

ECG-Based Task Force Criteria for Diagnosing ARVC/D

Repolarization Abnormalities

Minor Criteria

Inverted T waves in precordial leads (V2 and V3) in absence of right bundle branch block

Depolarization/Conduction Abnormalities

Major Criteria

Epsilon waves or localized prolongation (>110 ms) of QRS in right precordial leads (V1 – V3)

Minor Criteria

Late potentials (signal-average ECG)

Arrhythmias

Minor Criteria

Left bundle branch block type VT (sustained & nonsustained) by ECG, Holter or exercise testing.

Frequent ventricular extrasystoles (>1000/24 hrs) (Holter)

Incidence of Electrical Abnormalities on ECG, SAECG, and 24 Hour Holter Monitor in Several Series of Patients with ARVC/D

Table 2

Publications	Nava (1)	Peters (10)	Dalal (12)	Cox (13)	NIH Registry Data
# of Patients	N=136	N=265	N=69	N=42	N=95
1) Depolarization and Conduction Abnormalities					
a) Epsilon Waves	4%	23%	29%	10%	1%
b) Localized QRS >110msec in V ¹ , V ² , or V ³ (In Absence of RBBB)		70%	58%	26%	24%
c) QRS Duration Ratio $\frac{V^1 + V^2 + V^3}{V^4 + V^5 + V^6} > 1.2$		98%		35%	17%
d) Prolonged S Wave Duration			91% ^x	52% ^x	34% ^{xx}
Terminal Activation Delay (TAD)				71% ^{xxx}	
2) Repolarization Abnormalities					
Inverted T waves V ¹					18%
V ¹ and V ²					6%
V ¹ + V ² + V ³	19%	31%	81% ^{xxxx}	67%	16%
Beyond V ³	18%	23%			31%
Only V ⁴ , V ⁵ , V ⁶					3%
3) LBBB, VT on ECG Holter or Exercise Test					
a) Sustained VT			77%	42%	35%
b) 1000 PVCs/24 Hours on Holter			67%	28%	57%

^x Prolonged S wave duration from nadir of S wave to isoelectric line >55 msec in leads V₁ – V₂

^{xx} From nadir of S wave to end of depolarization (R')

^{xxx} (TAD) from nadir of S wave to end of all depolarization including an epsilon wave

^{xxxx} T ↓ V₁ – V₃ or beyond

Table 3

ECG Findings in RVOT Tachycardia and in ARVC/D

	RVOT	ARVC/D
T↓ V ₁ -V ₃	0–6%	37–81%
Prolonged S wave upstroke V ₁ -V ₃ (>55 msec)	4%	34–91%
Epsilon Waves	0%	1–29%
Superior QRS axis Of LBBB-PVCs or VT (positive in AVL)	0–4%	37–67%
Multiple VT Morphologies	0%	64%
QRS Duration in Lead I ≥ 120 msec during VT		
Positive SAECG	0–12%	50–80%

Data from references #1,2,6–8, 11, 13–17, 19 and from NIH Registry (Table 2)

Large % variation in categories may be due to centers who report data from patients with less or more advanced ARVC/D