Treatment of Arrhythmogenic Right Ventricular Cardiomyopathy/Dysplasia
An International Task Force Consensus Statement

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Arrhythmogenic right ventricular cardiomyopathy/dysplasia (ARVC/D) is an inheritable heart muscle disease that predominantly affects the right ventricle (RV) and predisposes to ventricular arrhythmias and sudden cardiac death (SCD).

In the last three decades, there have been a significant number of studies defining the pathogenesis, genetic aspects, and clinical manifestations of the disease (See ‘Etiology, pathogenesis, diagnosis and natural history’ in the online-only Data Supplement). In 1994 and 2010, an International Task Force (ITF) document proposed guidelines for the standardized diagnosis of ARVC/D based on electrocardiographic (ECG), arrhythmic, morphological, histopathological, and clinico-genetic factors.

The growing knowledge regarding arrhythmic outcome, risk factors, and life-saving therapeutic interventions, makes it particularly timely to critically address and place into perspective the issues relevant to the clinical management of ARVC/D patients. The present ITF consensus statement is a comprehensive overview of currently used risk stratification algorithms and approaches to therapy, either pharmacological or nonpharmacological, which often poses a clinical challenge to cardiovascular specialists and other practitioners, particularly those infrequently engaged in the management of ARVC/D.

This document should be regarded as a guide to clinical practice where rigorous evidence is still lacking, because of the relatively low disease prevalence and the absence of controlled studies. Recommendations are based on available data derived from nonrandomized and observational studies and consensus within the conference panelists. When development of prognostic-therapeutic algorithms was controversial, management decisions were recommended to be individualized.

Recommendation and level of evidence of specific management options were classified according to predefined scales, as outlined in Tables 1 and 2 (http://www.escardio.org/guidelines-surveys/esc-guidelines/about/Pages/rules-writing.aspx). Because randomized studies are not available, most consensus recommendations on treatment of ARVC/D are based on data derived from follow-up registries and/or experts opinions (i.e., level of evidence B or C).

All members of the writing group of this consensus document provided disclosure statements of all relationships that might present conflicts of interest.

Risk Stratification
The natural history of ARVC/D is predominantly related to ventricular electric instability which may lead to arrhythmic SCD, mostly in young people and athletes. In advanced disease, progression of RV muscle disease and left-ventricular involvement may result in right or biventricular heart failure. The available outcome studies are based on small patients cohorts followed for a relatively short follow-up period (Table 3). The estimated overall mortality rate varies among different studies, ranging from 0.08% per year during a mean follow-up of 8.5 years in the series by Nava et al. to 3.6% per year during a mean follow-up of 4.6 years in the series by Lemola et al.

The adverse prognosis of ARVC/D patients has been initially overestimated by reports from tertiary referral centres.

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largely composed of patients referred because of their high-risk status or severe clinical manifestations requiring specialized therapeutic interventions, such as catheter ablation or implantable defibrillator (ICD). 

Studies from community-based patient cohorts and clinical screening of familial ARVC/D reported a much lower overall annual mortality rates (<1%). These latter data provide a more balanced view of the natural history of ARVC/D, in which the disease may occur with no or relatively mild disability and without the necessity for major therapeutic interventions. 

The mechanism of SCD in ARVC/D is cardiac arrest due to sustained ventricular tachycardia (VT) or ventricular fibrillation (VF), which may occur as the first manifestation of the disease in young people without previous symptoms. 

Data from autopsy series and observational clinical studies on ARVC/D have provided a number of clinical predictors of adverse events and death. Table 2 reports the clinical variables identified as independent predictors of poor outcome including malignant arrhythmic events (ie, SCD, cardiac arrest due to VF, appropriate ICD interventions, or ICD therapy on fast VT/VF), non-SCD, or heart transplantation, which were found in at least one published multivariable analysis. Patients who have experienced sustained VT or VF are at highest risk of experiencing life-threatening arrhythmic events. 

Unexplained syncope has been associated with an increased arrhythmic risk in some but not in all studies. Note, unexplained syncope is defined as a loss of consciousness that: (i) occurs in the absence of documented ventricular arrhythmias and/or circumstances clearly leading to reflex-mediated changes in vascular tone or heart rate such as a micturition, defaecation, cough, or other similar conditions; (ii) remains unexplained after a detailed clinical evaluation aimed to exclude other cardiac or extracardiac causes. 

Other independent risk factors for adverse events include nonsustained VT on 24-h Holter monitoring, dilation/dysfunction of RV, left ventricle (LV), or both; male gender, compound and digenic heterozygosity of desmosomal-gene mutations; young age at the time of diagnosis, proband status, inducibility at programmed ventricular stimulation, amount of electroanatomic scar and electroanatomic scar-related fractionated electrograms, extent of T-wave inversion across precordial and inferior leads, low QRS amplitude and QRS fragmentation. 

**Electrophysiological Study**

Electrophysiological study (EPS) is a valuable diagnostic test for differential diagnosis between ARVC/D and idiopathic right ventricular outflow tract tachycardia and may provide useful information regarding the VT inducibility for optimization of detection/discrimination algorithms and effective antitachycardia pacing protocols in patients undergoing ICD implantation. However, conflicting data exist concerning the role of inducibility of sustained VT or VF for prediction of long-term arrhythmic outcome in ARVC/D patients. 

Discrepancies between the study results may be explained by differences in arrhythmic endpoints (ie, life-saving versus any appropriate ICD discharge). 

The largest multicentre studies on ARVC/D patients who received an ICD demonstrated that EPS is of limited value in identifying patients at risk of arrhythmic cardiac arrest because of its low predictive accuracy. In these studies, the reported incidence of ‘life-saving’ ICD discharges for treatment of fast VT or VF did not differ significantly in patients who were and were not inducible at EPS, regardless of the specific indication for ICD implantation. The study by Corrado et al on the outcome of 106 ARVC/D patients receiving an ICD for primary prevention reported that the positive and negative predictive value of inducibility for VT or VF was 55 and 70%, respectively. In this study, the type of ventricular tachyarrhythmia inducible at the time of EPS (ie, VT or VF) did not predict a statistically different arrhythmic outcome over the follow-up. The North American Multidisciplinary study on 98 ARVC patients receiving an ICD confirmed that inducible VT or VF at preimplant EPS did not predict appropriate interventions on fast VT or VF during a mean follow-up of 3.3 years. On the contrary, in the cohort of ARVC/D patients reported in the Johns Hopkins studies, inducibility was the most significant independent predictor of appropriate ICD firing. However, in the study by Bhonsale et the positive and negative predictive values of inducibility were 65 and 75%, respectively, and a sizeable proportion of patients experienced ICD interventions during follow-up despite a lack of inducibility of VT/VF. Moreover, the predictive value of inducibility for ‘life-saving’ ICD discharges was not demonstrated by either univariate or multivariate analysis. In asymptomatic patients, Bhonsale et

**Table 1. Classes of Recommendations**

<table>
<thead>
<tr>
<th>Classes of recommendations</th>
<th>Definition</th>
<th>Suggested wording to use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I</td>
<td>Evidence and/or general agreement that a given treatment or procedure is beneficial, useful, effective.</td>
<td>Is recommended/is indicated</td>
</tr>
<tr>
<td>Class II</td>
<td>Conflicting evidence and/or a divergence of opinion about the usefulness/efficacy of the given treatment of procedure.</td>
<td>Should be considered</td>
</tr>
<tr>
<td>Class IIa</td>
<td>Weight of evidence/opinion is in favor of usefulness/efficacy.</td>
<td>Should be considered</td>
</tr>
<tr>
<td>Class IIb</td>
<td>Usefulness/efficacy is less well established by evidence/opinion</td>
<td>May be considered</td>
</tr>
<tr>
<td>Class III</td>
<td>Evidence or general agreement that the given treatment or procedure is not useful/effective, and in some cases may be harmful</td>
<td>Is not recommended</td>
</tr>
</tbody>
</table>

**Table 2. Levels of Evidence**

<table>
<thead>
<tr>
<th>Level of evidence</th>
<th>Data derived from multiple randomized clinical trials or meta-analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level of evidence</td>
<td>Data derived from a single randomized clinical trial or large nonrandomized studies</td>
</tr>
<tr>
<td>Level of evidence</td>
<td>Consensus of opinion of the experts and/or small studies, retrospective studies, registries.</td>
</tr>
<tr>
<td>Risk factor</td>
<td>Definition</td>
</tr>
<tr>
<td>------------</td>
<td>------------</td>
</tr>
<tr>
<td>Cardiac arrest</td>
<td>Aborted SCD due to VF</td>
</tr>
<tr>
<td>Unstable sustained VT</td>
<td>Sustained (&gt;30 s) VT causing syncope or haemodynamic collapse</td>
</tr>
<tr>
<td>Sustained VT or VF</td>
<td>VT lasting &gt;30 s or VF</td>
</tr>
<tr>
<td>Syncope</td>
<td>Sustained (&gt;30 s) VT</td>
</tr>
<tr>
<td></td>
<td>Syncopal episodes unrelated to extracardiac causes and occurring in the absence of documented ventricular arrhythmias and/or circumstances clearly leading to reflex-mediated changes in vascular tone or heart rate</td>
</tr>
<tr>
<td></td>
<td>FAC % per unit decrease</td>
</tr>
<tr>
<td>LV dysfunction</td>
<td>Angiographic LV EF &lt;55%</td>
</tr>
<tr>
<td></td>
<td>Angiographic LV EF &lt;40%</td>
</tr>
<tr>
<td></td>
<td>Angiographic LV EF &lt;55%</td>
</tr>
<tr>
<td></td>
<td>Echocardiographic LV EF &lt;50%</td>
</tr>
<tr>
<td>RV dysfunction</td>
<td>Angiographic RV EF &lt;45%</td>
</tr>
<tr>
<td></td>
<td>FAC % per unit decrease</td>
</tr>
<tr>
<td>RV dilation</td>
<td>RV end-diastolic area, cm², per unit increase</td>
</tr>
<tr>
<td>Right-atrial dilation</td>
<td>Right atrium, short axis, mm, per unit increase</td>
</tr>
<tr>
<td>Biventricular dysfunction</td>
<td>Echocardiographic RV and LV dysfunction (EF &lt;50%)</td>
</tr>
<tr>
<td>Heart failure</td>
<td>Clinical signs of RV heart failure</td>
</tr>
<tr>
<td></td>
<td>Clinical signs or symptoms of congestive heart failure</td>
</tr>
</tbody>
</table>

(Continued)
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al 26 reported that the combination of ≥2 factors such as inducibility at EPS, proband status, nonsustained VT, and PVCs ≥1000/24 h, predicts an incremental risk of appropriate ICD interventions; however, a statistically significant association with life-saving shocks for treatment of rapid VT or VF has not been demonstrated. In the study by Saguner et al 33

### Table 3. Continued

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Definition</th>
<th>Patients, n</th>
<th>Study end point</th>
<th>HR/OR</th>
<th>95% CI</th>
<th>P-value</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young age</td>
<td>Per 5 yr increment</td>
<td>132</td>
<td>ICD interventions on rapid VT/VF</td>
<td>0.77</td>
<td>0.57–0.96</td>
<td>0.007</td>
<td>Corrado et al Circulation 200322</td>
</tr>
<tr>
<td></td>
<td>Per 1 yr increment</td>
<td>108</td>
<td>ICD interventions on rapid VT/VF</td>
<td>N/A</td>
<td>N/A</td>
<td>0.03</td>
<td>Link et al JACC 201423</td>
</tr>
<tr>
<td>Male gender</td>
<td></td>
<td>215</td>
<td>Composite (cardiac arrest in 9%, ICD intervention in 22%, sustained VT in 69%)</td>
<td>1.8</td>
<td>1.2–2.8</td>
<td>0.004</td>
<td>Bhonsale et al Circ AE 201331</td>
</tr>
<tr>
<td></td>
<td></td>
<td>134</td>
<td>Composite (SCD in 5%, cardiac arrest 27%, sustained VT 64%, ICD shock 5%)</td>
<td>2.76</td>
<td>1.19–6.41</td>
<td>0.02</td>
<td>Rigato et al Circ Gen 201332</td>
</tr>
<tr>
<td>Complex genotype</td>
<td>Compound or digenic heterozygosity</td>
<td>134</td>
<td>Composite (SCD in 5%, cardiac arrest 27%, sustained VT 64%, ICD shock 5%)</td>
<td>3.71</td>
<td>1.54–8.92</td>
<td>0.003</td>
<td>Rigato et al Circ Gen 201332</td>
</tr>
<tr>
<td>Proband status</td>
<td>First family member affected by the genetic defect who seeks medical attention because of the occurrence of clinical manifestations</td>
<td>215</td>
<td>Composite (cardiac arrest in 9%, ICD intervention in 22%, sustained VT in 69%)</td>
<td>7.7</td>
<td>2.8–22.5</td>
<td>&lt;0.001</td>
<td>Bhonsale et al Circ AE 201331</td>
</tr>
<tr>
<td>Inducible VT/VF</td>
<td>VT or VF that lasted &gt;30 s or required termination because of haemodynamic compromise</td>
<td>84</td>
<td>Any appropriate ICD intervention</td>
<td>4.5</td>
<td>1.4–15.0</td>
<td>0.013</td>
<td>Wichter et al Circulation 200428</td>
</tr>
<tr>
<td></td>
<td></td>
<td>60</td>
<td>Any appropriate ICD intervention</td>
<td>2.16</td>
<td>0.94–5.0</td>
<td>0.069*</td>
<td>Link et al JACC 201423</td>
</tr>
<tr>
<td></td>
<td></td>
<td>N/A</td>
<td>ICD intervention on fast VT/VF</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>Saguner, Am J Cardiol 201333</td>
</tr>
<tr>
<td></td>
<td>VT that lasted &gt;30 s or required termination because of haemodynamic compromise. Induction of VF not considered</td>
<td>62</td>
<td>Composite (cardiac death in 13%, heart transplantation in 10%, unstable VT/VF in 70%, syncope in 7%).</td>
<td>2.5</td>
<td>1.0–6.2</td>
<td>0.04</td>
<td>Saguner et al Circulation 200428</td>
</tr>
<tr>
<td>Extent of electroanatomic scar on RV endocardial voltage mapping</td>
<td>Low-voltage (&lt;0.5 mV) areas on bipolar electroanatomic voltage mapping. Per 5% increment.</td>
<td>69</td>
<td>Composite arrhythmic (SCD in 5%, ICD intervention in 37%, sustained VT in 58%)</td>
<td>1.6</td>
<td>1.2–1.9</td>
<td>&lt;0.001</td>
<td>Migliore et al Circ AE 201334</td>
</tr>
<tr>
<td>Fragmented electrograms on RV endocardial voltage mapping</td>
<td>Multiple (&gt;3) discrete deflections, amplitude &lt;1.5 mV, and duration &gt;100 ms</td>
<td>95</td>
<td>Any appropriate ICD intervention</td>
<td>21.2</td>
<td>1.8–251.8</td>
<td>0.015</td>
<td>Santangeli et al Heart Rhythm 201235</td>
</tr>
<tr>
<td>T-wave inversion in inferior leads</td>
<td>Negative T-waves in leads II, III, aVF</td>
<td>108</td>
<td>Any appropriate ICD intervention</td>
<td>N/A</td>
<td>N/A</td>
<td>0.02</td>
<td>Link et al JACC 201442</td>
</tr>
<tr>
<td></td>
<td>Inverted T waves in 2 of 3 inferior leads</td>
<td>111</td>
<td>Composite (6% cardiac death; 8% heart transplantation; 16% VF; 67% sustained VT; 3% arrhythmic syncope)</td>
<td>2.4</td>
<td>1.2–5.2</td>
<td>0.02</td>
<td>Saguner, AJC 201443</td>
</tr>
<tr>
<td>Extent of T-wave inversion</td>
<td>Inverted T waves in ≥3 precordial leads</td>
<td>215</td>
<td>Composite arrhythmic (cardiac arrest in 9%, ICD intervention in 22%, sustained VT in 69%)</td>
<td>4.2</td>
<td>1.2–14.5</td>
<td>0.03</td>
<td>Bhonsale et al Circ AE 201331</td>
</tr>
<tr>
<td>QRS fragmentation</td>
<td>Additional deflections/notches at the beginning of the QRS, on top of the R wave, or in the nadir of the S wave in either 1 right precordial lead or in &gt;1 lead including all remaining leads</td>
<td>111</td>
<td>Composite (6% cardiac death; 8% heart transplantation; 16% VF; 67% sustained VT; 3% arrhythmic syncope)</td>
<td>2.7</td>
<td>1.1–6.3</td>
<td>0.03</td>
<td>Saguner, AJC 201443</td>
</tr>
<tr>
<td>Precordial QRS amplitude ratio</td>
<td>Sum of QRS voltages in V1–V3/sum of QRS voltages in V1–V6&lt;0.48</td>
<td>111</td>
<td>Composite (6% cardiac death; 8% heart transplantation; 16% VF; 67% sustained VT; 3% arrhythmic syncope)</td>
<td>2.9</td>
<td>1.4–6.2</td>
<td>0.005</td>
<td>Saguner AJC 201444</td>
</tr>
</tbody>
</table>

The list includes predictor variables that have been associated with an increased risk of major arrhythmic events (ie, SCD, appropriate ICD interventions, or ICD therapy on fast VT/VF) in at least one published multivariable analysis in prospective studies.

FAC, fractional area change; EF, ejection fraction; LV, left ventricle; RV, right ventricle; SCD, sudden cardiac death; VF, ventricular fibrillation; and VT, ventricular tachycardia.

*Borderline statistical significance.
inducible VT was an independent predictor of composite end point including cardiac death, heart transplantation, unstable VT/VF, and syncope.

According to available studies on ARVC/D patients, the protocol of programmed ventricular stimulation should include a minimum of two drive-cycle lengths and three ventricular extrastimuli while pacing from two RV sites (apex and RV outflow tract); inducibility is defined as the induction of either VF or sustained VT, ie, lasting >30 s or requiring termination because of haemodynamic compromise.21,22,25,41

Recent studies showed that demonstration and quantification of bipolar RV electroanatomic scar area34 as well as identification of scar-related fractionated electrogartns and late potentials35 on endocardial voltage mapping during EPS may provide significant added value for arrhythmic risk assessment in ARVC/D. Because endocardial voltage mapping is an invasive, expensive, and highly operator-dependent technique with a significant risk of inaccurate interpretation of low-voltage recordings in areas of normal myocardium due to suboptimal catheter contact, it is not recommended as a routine diagnostic tool.

Recommendations

- EPS should be considered in the diagnosis and/or evaluation of patients with suspected ARVC/D (class IIa).
- Programmed ventricular stimulation may be considered for arrhythmic risk stratification of asymptomatic ARVC/D patients (class IIb).
- Endocardial voltage mapping may be considered in the diagnostic and prognostic evaluation of ARVC/D patients (class IIb).

Follow-up

Patients with ARVC/D should undergo lifelong clinical follow-up to periodically evaluate new onset or worsening of symptoms, progression of morphological and/or functional ventricular abnormalities, and ventricular arrhythmias in order to reassess the risk of SCD and optimize the treatment. Cardiac evaluation of affected patients including resting 12-lead ECG, echocardiography, 24-h Holter monitoring, and exercise testing (for detection of effort-induced ventricular arrhythmias) should be performed on a regular basis (every 1–2 years) depending on the age, symptoms, and disease severity.

Due to the age-related penetrance of ARVC/D, healthy gene carriers and family members should also be offered repeat clinical assessment (every 2–3 years), mostly during adolescence and young adulthood.

Therapy

The most important objectives of clinical management of ARVC/D patients include: (i) reduction of mortality, either by arrhythmic SCD or death from heart failure; (ii) prevention of disease progression leading to LV, LV, or biventricular dysfunction and heart failure; (iii) improvement of symptoms and quality of life by reducing/abolishing palpitations, VT recurrences, or ICD discharges (either appropriate or inappropriate); and (iv) limiting heart failure symptoms and increasing functional capacity. Therapeutic options consist of lifestyle changes, pharmacological treatment, catheter ablation, ICD, and heart transplantation.

Lifestyle Changes

A link has been established between SCD and intense exertion in young individuals with ARVC/D. Competitive sports activity has been shown to increase the risk of SCD by five-fold in adolescent and young adults with ARVC/D.42 Early (ie, presymptomatic) identification of affected athletes by preparticipation screening and their disqualification from competitive sports activity may be “life-saving.”8,43

In addition, physical exercise has been implicated as a factor promoting development and progression of the ARVC/D phenotype. Kirchhof et al44 demonstrated that in heterozygous plakoglobin-deficient mice, endurance training accelerated the development of RV dilatation, dysfunction, and ventricular ectopy, suggesting that chronically increased ventricular load might contribute to worsening of the ARVC/D phenotype. It has been postulated that impairment of myocyte cell-to-cell adhesion may lead to tissue and organ vulnerability, which may promote myocyte death especially during mechanical stress, which occurs during competitive sports activity.45,46 Studies in humans confirmed that endurance sports and frequent exercise increase age-related penetrance, risk of VT/VF, and occurrence of heart failure in ARVC/D desmosomal-gene carriers.47,48

Recommendations

- It is recommended that patients with a definite diagnosis of ARVD/C not participate in competitive and/or endurance sports (Class I).
- Patients with a definite diagnosis of ARVD/C should be restricted from participation in athletic activities, with the possible exception of recreational low-intensity sports (Class IIa).
- Restriction from competitive sports activity may be considered in ARVC/D family members with a negative phenotype, either healthy gene carriers (class IIa) or with unknown genotype (class IIb).

Pharmacological Therapy

Pharmacological options in ARVC/D treatment consist of antiarrhythmic agents, β-blockers, and heart failure drug therapy.

Antiarrhythmic Drugs

The aim of antiarrhythmic drug (AAD) therapy in patients with ARVC/D is to improve the quality of life by preventing symptomatic ventricular arrhythmias. There are no prospective and randomized trials on AAD therapy in ARVC/D and systematic comparison of treatment strategies.

Moreover, the assessment of efficacy of specific AAD therapy is difficult because ARVC/D patients tend to have multiple arrhythmic events over time and drugs are often changed.41,49 Available data are limited to case-control studies, retrospective analyses, and clinical registries. Hence, indication for AAD therapy and choice of drug are based on an empirical approach resulting from extrapolation from other diseases, personal experience, consensus, and individual decisions.

The available evidence suggests that amiodarone (loading dose of 400–600 mg daily for 3 weeks and then maintenance dose of 200–400 mg daily), alone or in combination with β-blockers, is the most effective drug for preventing symptomatic ventricular arrhythmias with a relatively low
proarrhythmic risk even in patients with ventricular dysfunction, although its ability to prevent SCD is unproved. Corrado et al. reported that the majority of life-saving ICD interventions in high-risk patients occurred despite concomitant AADs, a finding supporting the concept that AAD therapy may not confer adequate protection against SCD.

Recommendations
- AADs are recommended as an adjunct therapy to ICD in ARVC/D patients with frequent appropriate device discharges (class I).
- The use of AADs should be considered to improve symptoms in patients with frequent premature ventricular beats and/or nonsustained VT (class IIa).
- AADs may be considered as an adjunct therapy to catheter ablation without a back-up ICD in selected ARVC/D patients with recurrent, haemodynamically stable VT (class IIb).
- AAD treatment of asymptomatic ARVC/D patients without documented ventricular arrhythmias and healthy gene carriers is not recommended (class III).

Beta-blockers
Ventricular arrhythmias and cardiac arrest in ARVC/D are frequently triggered by adrenergic stimulation and occur during or immediately after physical exercise. Autonomic dysfunction with increased sympathetic stimulation of ventricular myocardium and subsequent reduction of β-adrenoceptor density was demonstrated by Wichter et al. with the use of radionuclide imaging and quantitative positron emission tomography.

The indication for the use of β-blocker drugs in ARVC/D relies on their proven efficacy to prevent effort-induced ventricular arrhythmias, their proven efficacy in heart failure management, and their potential but unproven ability to hinder myocardial disease progression by lowering RV wall stress.

Because studies are not available to compare the efficacy of individual β-blockers and to define the most effective dosage, we recommend using nonvasodilating β-blockers titrated to maximum tolerated dose for age and weight.

Recommendations
- Beta-blocker therapy is recommended in ARVC/D patients with recurrent VT, appropriate ICD therapies, or inappropriate ICD interventions resulting from sinus tachycardia, supraventricular tachycardia, or atrial fibrillation/flutter with high-ventricular rate (class I).
- Beta-blocker therapy should be considered in all patients with ARVD/C irrespective of arrhythmias (class IIa).
- The prophylactic use of β-blockers in healthy gene carriers is not recommended (class III).

Preload-reducing Drug Therapy
Fabritz et al. provided experimental evidence that ventricular preload-reducing therapy prevents or tempers the development of ARVC/D in genetically susceptible murine hearts. Therapy with furosemide and nitrates completely prevented training-induced development of RV enlargement and normalized VT inducibility, thereby rendering treated plakoglobin-deficient mice phenotypically indistinguishable from their trained wild-type littermates.

Preload-reducing drug therapy is not yet part of clinical practice because the results of the animal studies demonstrating its beneficial effects require validation in other ARVC/D models and patients.

Heart Failure and Antithrombotic Drug Therapy
The prevalence of RV or biventricular dysfunction leading to progressive heart failure and death in ARVC/D is variable in the published series, mostly depending on the selection criteria of patients, whether referred for arrhythmias or heart failure. Left-ventricular involvement was originally considered an end-stage complication of ARVC/D, occurring late during the disease course and leading ultimately to biventricular pump failure. More recently, genotype–phenotype correlations have shown early and greater LV involvement in genetically predisposed ARVC/D patients.

In ARVC/D, thromboembolic complications may result from intracardiac thrombus formation into ventricular aneurysms, sacculations, or ventricular dilatation due to either global or regional ventricular dysfunction. A retrospective study by Wlodarska et al. on 126 ARVC/D patients with severe RV dilatation reported a 0.5% annual incidence rate of thromboembolic complications during a mean follow-up period of 99±64 months.

Recommendations
- For ARVC/D patients who developed right- and/or left-sided heart failure standard pharmacological treatment with angiotensin-converting-enzyme inhibitors, angiotensin II receptor blockers, β-blockers, and diuretics is recommended (class I).
- Long-term oral anticoagulation is generally indicated for secondary prevention in patients with documented intracavitary thrombosis or venous/systemic thromboembolism (class I).
- For ARVC/D patients with asymptomatic RV and/or LV dysfunction treatment with angiotensin-converting-enzyme inhibitors or angiotensin II receptor blockers may be considered (class IIb).
- Prophylactic anticoagulation for primary prevention of thromboembolism on the basis of ventricular dilatation/dysfunction, either global or regional, is not recommended (class III).

Catheter Ablation
Catheter ablation is a therapeutic option for ARVC/D patients who have VT. Fibrofatty replacement of RV myocardium creates scar regions that are regarded as arrhythmogenic substrate for VT. Ventricular tachycardia is the result of a scar-related macro-reentry circuit, similar to that observed in the post-myocardial infarction setting, which is suitable for mapping and interruption by catheter ablation. Catheter ablation may be guided by either conventional electrophysiological or substrate-based mapping during sinus rhythm.

Fontaine et al. first studied the effects of direct current fulguration and demonstrated the feasibility of VT ablation...
in ARVC/D. Subsequently, several studies have reported on acute and long-term results of endocardial catheter ablation of VT using radiofrequency current.\(^{63-73}\) Overall, acute success was achieved in 60% to 80% of patients, whereas the recurrence rates during long-term follow-up of 3 to 5 years were as high as 50% to 70% (online-only Data Supplement, Table S1). The high frequency of VT recurrences and the discrepancy between the successful acute results and the unfavourable long-term outcome have been explained by the progressive nature of the ARVC/D substrate (ie, fibrofatty scar), which predisposes to the occurrence of multiple reentry circuits and new arrhythmogenic foci over time.\(^{10,68}\) Recently, studies have suggested that epicardial location of some VT reentry circuits, which reflects the propensity of ARVC/D lesion to originate and progress from the epicardium, may partly explain the failure of conventional endocardial mapping/catheter ablation. Garcia et al\(^{70}\) first reported the feasibility and efficacy of epicardial catheter ablation in ARVC/D patients who underwent an epicardial approach after previously failed endocardial VT mapping/ablation procedures. In these patients, the extent of electroanatomical scar area at voltage mapping was larger on the epicardial side of the RV wall than on the endocardium. Complete success was achieved in 85% of cases (partial success in 92%) and 77% of patients were free of VT during 18 months of follow-up. Phillips et al\(^{72}\) compared the efficacy of traditional electrophysiological VT mapping/catheter ablation with other strategies including substrate-based and epicardial catheter approaches. The recurrences of VT were significantly reduced irrespective of the mapping/ablation strategy. The cumulative freedom from VT following procedures using 3D-electroanatomical mapping and/or epicardial approach was significantly greater than conventional ablation, although the recurrence rates remain considerable. Freedom from VT after epicardial ablation of 64 and 45% at 1 and 5 years was found, which was significantly improved compared with studies using the endocardial approach. According to Berruezo et al,\(^{71}\) complete scar dechannelling with elimination of either endo or epicardial scar conducting channels (ie, intrascar, interscar, or between scar and valvular annuli) in addition to ablation of clinical VT is a promising approach to improve long-term success rate of catheter ablation.

According to available data, catheter ablation of VT in ARVC/D patients should be considered a potentially effective strategy for eliminating frequent VT episodes and ICD shocks rather than a curative therapeutic approach, until long-term efficacy has been consistently documented. Catheter ablation has not been proved to prevent SCD and should not be looked on as an alternative to ICD therapy in ARVC/D patients with VT, with the exception of selected cases with a drug refractory, haemodynamically stable, single morphology VT.\(^{22}\) Additional AAD therapy and repeated ablation procedures as well as back-up ICD implantation are required to provide clinical control of VT and SCD prevention.

**Recommendations**

- Catheter ablation of VT is recommended in ARVC/D patients with incessant VT or frequent appropriate ICD interventions on VT despite maximal pharmacological therapy, including amiodarone (class I).
- An epicardial approach to VT ablation is recommended in patients who fail one or more attempts of endocardial VT ablation (class I).
- Catheter ablation of VT should be considered in ARVC/D patients with incessant VT or frequent appropriate ICD interventions on VT who have failed pharmacological therapy other than amiodarone (class IIa).
- A combined endocardial/epicardial VT ablation approach as an initial ablation strategy should be considered, provided that the operator and electrophysiological laboratory are experienced performing epicardial VT ablation in patients with ARVC/D (class IIa).
- Catheter ablation of VT may be considered in ARVC/D patients with incessant VT or frequent appropriate ICD interventions on VT who have not failed pharmacological therapy and who do not wish to be treated with pharmacological therapy (class IIb).
- Catheter ablation may be indicated as first choice therapy without a back-up ICD for selected patients with drug-refractory, haemodynamically stable, single-morphology VT (class III).
- Catheter ablation is not recommended as an alternative to ICD for prevention of SCD in ARVC/D (class III).

**Implantable Defibrillator Therapy**

Implantable defibrillator therapy is the most logical therapeutic strategy for patients with ARVC/D, because the natural history is primarily characterized by the risk of SCD and, only secondarily, by contractile dysfunction leading to progressive heart failure. Prospective randomized trials are currently not available for ethical reasons and because of practical limitations predominantly linked to relatively low disease prevalence and low event rate. The available data, coming from observational studies/registries of large populations of ARVC/D patients, have established efficacy and safety of ICD therapy.\(^{22,25,26,28,74-81}\) The main results of available studies on ICD therapy in ARVC/D are summarized in the online-only Data Supplement, Table S2. These studies consistently document that ICD successfully interrupts lethal ventricular tachyarrhythmias and improves long-term outcome of selected high-risk ARVC/D patients. Overall, between 48 and 78% of patients received appropriate ICD interventions during a mean follow-up period of 2 to 7 years after implantation. Many of these patients experienced multiple ICD discharges during this period and VT storm was not infrequently reported. In most studies, the survival benefit of the ICD was evaluated by comparing the actual patient survival rate with the projected freedom of ICD interventions for fast VT (>240 bpm) or VF (ie, ‘life- saving’ ICD interventions), which were used as a surrogate for aborted SCD, based on the assumption that these tachyarrhythmias would have been fatal without termination by the device.\(^{22,25,26,77}\) The end point was reached by device interrogation and review of stored electrocardiograms regarding ICD interventions in response to fast VT/VF during follow-up. In the largest multicentre study, the fast VT/VF-free survival rate was 72% at 36 months compared with the actual patient survival of 98%, with an estimated survival benefit of 26%.\(^{22}\) The largest single-center experience found an estimated improvement of overall survival of 23, 32
and 35% after 1, 3 and 7 years of follow-up, respectively. These results were confirmed by other series reporting rates of life-saving ICD interventions in 30% to 50% of patients during follow-up. Despite the relatively short follow-up of the available studies, the time between implantation and the first appropriate discharge was ≥1 year in a large proportion of patients with a maximal interval of 5.5 years. This finding suggests that ICD implantation is a lifelong preventive measure with life-saving interventions occurring even after particularly long phases of dormant ventricular electric instability.

It is important to recognize that survival benefit of ICD treatment is obtained at the expense of significant complications during follow-up, with estimated rates of lead/device related complications and inappropriate ICD therapies of 3.7%/yr and 4.4%/yr, respectively (online-only Data Supplement, Table S2). Detailed information on ICD-related complications in the published ICD studies is provided by the recent meta-analysis by Schinkel. In the long-term study (80±43 months) by Wichter et al, 37 of 60 (62%) ARVC/D patients had a total of 53 serious adverse events (31 lead-related), 10 occurring during the perioperative phase and 43 during follow-up. This high rate of lead-related adverse events may be explained by the peculiar ARVC/D pathobiology which leads to progressive loss of myocardium with fibrofatty replacement, also affecting the site of RV lead implantation. In this regard, Corrado et al reported that ≈4% of ARVC/D patients required an additional septal lead owing to loss of ventricular sensing/pacing functions at the apical RV free wall during a follow-up of 3.3 years. Therefore, particular attention should be paid to progressive loss of R-wave sensing amplitude during follow-up, which may compromise adequate device function and may indicate disease progression.

Inappropriate ICD interventions occur in 10% to 25% of patients with ARVC/D, mostly at young age, and are usually caused by sinus tachycardia or atrial tachyarrhythmia (online-only Data supplement, Table S2). Inappropriate interventions are painful and may have a profound clinical and psychological impact on patients. The incidence of inappropriate ICD discharges can be lowered by appropriate ICD programming and administration of β-blockers or sotalol. Although the use of dual-chamber detection algorithms offers the potential to reduce the number of inappropriate interventions by improving discrimination of ventricular from supraventricular arrhythmias, an additional lead in atrium predisposes to a high risk of inappropriate interventions by consensus, even in the absence of life-threatening ventricular arrhythmias. Because the specific arrhythmic risk of ventricular dysfunction is still underestimated for patients with ARVC/D, the inclusion of this clinical variable into the high-risk category was based on extrapolation from other cardiomyopathies and personal experience.

The low-risk category comprises probands and relatives without risk factors as well as healthy gene carriers who show a low rate of malignant arrhythmic events (estimated annual event rate <1%/year) over a long-term follow-up and do not require any treatment, including ICD therapy.

Between the two categories there are ARVC/D patients with ≥1 risk factors who are deemed to have an intermediate risk (estimated annual event rate between 1 and 10%/yr). Among the consensus experts there was general agreement that syncope, non sustained ventricular tachycardia (NSVT), or moderate ventricular dysfunction, either RV (RV fractional area change between 24 and 17% or RV EF between 40 and 36%), or left-ventricular (LV EF between 45 and 36%), are ‘major’ risk factors that justify (weight of opinion in favor of ICD) a prophylactic ICD. On the other hand, there was general consensus that the other factors reported in Table 3 (‘minor’ risk factors) are associated with a risk of major arrhythmic events not sufficiently high (or controversial) to warrant systematic ICD implantation for primary prevention (weight of opinion against ICD). The decision to implant an ICD in patients of this category should be made on individual basis, by assessing the overall clinical profile, the age, the strength of the risk factor identified, the level of SCD risk that is acceptable to the patient, and the potential risk of inappropriate interventions and complications.

It is noteworthy that indications for ICD implantation may vary in different countries as a consequence of several non-clinical factors such as cultural background, socio-economic conditions, health system, availability of advanced technology, cost–benefit considerations, and liability. Compared with the conservative approach of many European countries, the current threshold for decision to implant an ICD in the USA is lower. It is particularly important to outline the potential risk of inappropriate ICD implants due to a false diagnosis of ARVC/D based on misinterpretation of imaging studies including cardiac magnetic resonance.

**Recommendations**

- Implantation of an ICD is recommended in ARVC/D patients who have experienced ≥1 episodes of haemodynamically unstable, sustained VT or VF (class I).
- Implantation of an ICD is recommended in ARVC/D patients with severe systolic dysfunction of the RV, LV, or both, irrespective of arrhythmias (class I).
Implantation of an ICD should be considered in ARVC/D patients who have experienced ≥1 episodes of haemodynamically stable, sustained VT (class IIa).

Implantation of an ICD should be considered in patients who have ‘major’ risk factors such as unexplained syncope, moderate ventricular dysfunction, or NSVT (class IIa).

Implantation of an ICD may be considered in patients with ‘minor’ risk factors after a careful discussion of the long-term risks and benefits of ICD implantation (class IIb).

Prophylactic ICD implantation is not recommended in asymptomatic ARVC/D patients with no risk factors or healthy gene carriers (class III).

Device Selection
A single-chamber ICD system is recommended in order to minimize the incidence of long-term lead-related complications, mostly in young patients.

Experience with ICD therapy consistently highlights the beneficial effect of antitachycardia pacing which is highly effective in terminating VT episodes in ARVC/D patients. The precise clinical role of leadless subcutaneous ICD in patients with ARVC/D remains to be defined. A decision whether to implant a leadless device needs to be patient specific, balancing lead-related complications with the likelihood of recurrent VT that may be effectively pace-terminated.

Additional cardiac resynchronization therapy appears reasonable for those ARVC/D patients with a LV EF ≤35% and a wide QRS with a left bundle-branch block pattern, even though clinical benefit is extrapolated from resynchronization therapy in other disease states. Right ventricular resynchronization therapy has been proposed as a therapy for patients with congenital heart disease and chronic RV heart failure, however, no data are available concerning the clinical and haemodynamic effects of RV pacing in ARVC/D patients with RV dysfunction and a wide QRS with right bundle-branch block pattern.

Heart Transplantation
Arrhythmogenic right-ventricular cardiomyopathy/dysplasia patients with untreatable heart failure or uncontrollable ventricular tachyarrhythmias may require heart transplantation. Tedford et al. reported the Johns Hopkins Registry experience with 18 ARVC/D patients (61% males; mean age 40±14 year) undergoing heart transplantation. One-year after transplant, the survival was 94 and 88% of patients were alive at an average post-transplant follow-up of 6.2±4.8 years.

Heart transplantation is recommended as a final therapeutic option in ARVC/D patients with either severe, unresponsive congestive heart failure or recurrent episodes of VT/ VF which are refractory to catheter (and surgical) ablation in experienced centres and/or ICD therapy.

Other Surgical Therapies
There is currently no clinical role of surgical therapies such as RV cardiomyoplasty, RV disarticulation, beating heart cryoablation, and left cardiac sympathetic denervation in the treatment of patients with ARVC/D.

Figure 1. Flow chart of risk stratification and indications to ICD implantation in ARVC/D. Based on the available data on annual mortality rates associated to specific risk factors, the estimated risk of major arrhythmic events in the high-risk category is >10%/yr, in the intermediate ranges from 1 to 10%/yr, and in the low-risk category is <1%/yr. Indications to ICD implantation were determined by consensus taking into account not only the statistical risk, but also the general health, socioeconomic factors, the psychological impact and the adverse effects of the device. SCD, sudden cardiac death; VF, ventricular fibrillation; VT, ventricular tachycardia; RV, right ventricle; and LV, left ventricle. *See the text for distinction between major and minor risk factors.
Conclusions

The therapeutic management of patients with ARVC/D has evolved over the years and continues to be an important challenge. To further improve risk stratification and treatment of patients, more information is needed on the natural history, long-term prognosis, and risk assessment. Special attention should be focused on the identification of patients who would benefit from ICD implantation in comparison to pharmacological and other nonpharmacological approaches. Data from prospective studies/registries with larger number of patients and longer follow-up as well as data obtained from multicentre randomized controlled trials are required to provide evidence-based recommendations for the best care of ARVC/D patients.

Current therapeutic and preventive measures are palliative, not curative. The definitive cure of ARVC/D will be based on the discovery of the molecular mechanisms that are involved in the etiology and pathogenesis of the disease.

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ETIOLOGY, PATHOGENESIS, DIAGNOSIS
AND NATURAL HISTORY OF ARVC/D

The main pathologic feature of ARVC/D is the progressive loss of RV myocardium with replacement by fibrofatty tissue. The clinical profile of ARVC/D was first reported in 1982 as a new clinical entity with the original designation of “dysplasia”, since it was initially believed to be a developmental defect of the RV myocardium. This concept has evolved into the current perspective of a genetically determined “cardiomyopathy”.

A familial incidence is present in more than half the patients with ARVC/D. Molecular genetic studies showed that ARVC/D is a “desmosomal” cardiomyopathy resulting from genetically defective cell-adhesion proteins such as plakoglobin, plakophilin-2, desmoplakin, desmoglein-2, and desmocollin-2. The diagnostic yield of desmosomal gene testing in clinical cases of ARVC/D is approximately 50%. A few additional causative mutations have also been identified in nondesmosomal genes, which account for distinct phenotypic characteristics in comparison with typical desmosomal gene variants.

In the classic disease phenotype, RV lesions progress over time to global RV dysfunction, while left ventricular (LV) involvement occurs late during the disease course and may lead to biventricular pump failure. Genotype-phenotype correlation studies have identified clinical variants characterized by early and greater LV involvement, which may either parallel (“biventricular”) or exceed (“left dominant”) the severity of RV disease. These findings support the concept of ARVC/D as a genetically determined heart muscle disease of the entire heart and, thus, the use of the broader term of “arrhythmogenic cardiomyopathy”, which encompasses all the disease phenotypic expressions. The present consensus document refers to the original ARVC/D form which has been the focus of the existing studies of the last three decades.
The estimated prevalence of ARVC/D in the general population ranges from 1 in 2000 to 1 in 5000, but this figure may be low because many cases escape clinical diagnosis. Previous studies consistently demonstrated a male predominance, suggesting that men develop a more severe disease phenotype most likely because of a direct influence of sex hormones on disease pathobiology and development of arrhythmogenic myocardial substrate. Although ARVC/D has been reported in human populations of different ethnicity, it is unknown if the disease is equally prevalent in different geographic areas. In the past, the misconception that ARVC/D was a Venetian disease relied on the unawareness of its clinical and pathologic features in other countries, where it remained largely underdiagnosed by clinicians and pathologists for a long time.

The clinical manifestations of the disease usually occur between the second and forth decade of life and mostly consist of cardiac arrest due to VF, ventricular arrhythmias with a left bundle branch block (LBBB) morphology, ECG depolarization/repolarization changes typically localized to right precordial leads, and structural alterations and global/regional dysfunction of the RV. The following phases in the disease natural history can be considered: 1) “Concealed” characterised by no or subtle RV structural changes, with or without minor ventricular arrhythmias, during which SCD may occasionally be the first manifestation of the disease, mostly in young people during competitive sports or intense physical exercise. 2) “Overt electrical disorder” in which symptomatic RV arrhythmias possibly leading to sudden cardiac arrest are associated with overt RV functional and structural abnormalities. 3) “RV failure” caused by the progression and extension of RV muscle disease that provoke global RV dysfunction with relatively preserved LV function. 4) “Biventricular pump failure” caused by pronounced LV involvement. At this stage, ARVC/D mimics biventricular dilated cardiomyopathy of other causes leading to congestive heart failure.

In the early disease phase, VF may reflect acute ventricular electrical instability related to “hot phases” of the disease, with acute myocyte death and reactive inflammation, often characterized by dynamic T-wave inversion, ST segment elevation, and myocardial enzyme release. Older patients with a long-lasting disease more often experience scar-related, re-entrant sustained VT.
Ventricular arrhythmias are accentuated during or immediately after exercise, and participation in competitive athletics has been associated with an increased risk for cardiac arrest.\textsuperscript{25-29} More recently, gap junction remodelling and ion channel interference preceding the fibro-fatty scar have been postulated as alternative substrates for anisotropic and delayed intraventricular conduction predisposing to lethal arrhythmias in the pre-phenotypic phase of the disease, as supported by experimental animal models.\textsuperscript{30-34}

According to the diagnostic criteria proposed by an International Task Force (ITF) in 1994, the diagnosis of ARVC/D is based on the presence of major and minor criteria encompassing electrocardiographic, arrhythmic, morphological, histopathologic, and genetic factors.\textsuperscript{35} The criteria were initially designed to provide adequate specificity for ARVC/D among index cases with overt clinical manifestations and to guide differential diagnosis from other conditions such as dilated cardiomyopathy or idiopathic RV outflow tract tachycardia. However, the original diagnostic criteria lacked sensitivity for identification of early/minor phenotypes, particularly in the setting of familial ARVC/D and did not provide quantitative values for morphological and functional RV abnormalities.\textsuperscript{7, 36-37} In 2010, a revision of ITF diagnostic criteria was published with the aim of improving diagnostic sensitivity, but with the important requisite of maintaining diagnostic specificity.\textsuperscript{21}
### SUPPLEMENTARY TABLES

**Supplementary Table 1. Major Series of Catheter Ablation of Ventricular Tachycardia in Arrhythmogenic Right Ventricular Cardiomyopathy/Dysplasia**

<table>
<thead>
<tr>
<th>Author (year)</th>
<th>Patients (n (men))</th>
<th>Ablation technique</th>
<th>Complete acute success* (%)</th>
<th>Procedure-related complications</th>
<th>Follow-up</th>
<th>Mean (months)</th>
<th>VT Recurrences (%)</th>
<th>Deaths or HT</th>
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* targeted VT(s) non re-inducible by programmed ventricular stimulation.  
HT=heart transplantation; HF=heart failure; NC=non cardiac; MI=myocardial infarction
Supplementary Table 2. Major Series of Implantable Cardioverter Defibrillator in Arrhythmogenic Right Ventricular Cardiomyopathy/Dysplasia

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<th>First Author</th>
<th>Year</th>
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<th>Follow-up (months)</th>
<th>Primary prevention (%)</th>
<th>Mortality overall (%)</th>
<th>Appropriate interventions (%)</th>
<th>Life-saving interventions (%)</th>
<th>Inappropriate Interventions (%)</th>
<th>Complications (%)</th>
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<td>65±42</td>
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<td>Corrado⁵⁸</td>
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<td>58±35</td>
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</table>

5-year cumulative frequency for first appropriate ICD discharge MC: multicenter study; N/A: not available; SC: single-center study


