Consensus document

Diagnostic work-up of arrhythmogenic right ventricular cardiomyopathy by cardiovascular magnetic resonance

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Cardiovascular magnetic resonance (CMR) has become a widespread diagnostic tool. Since its introduction, CMR has been used to image patients with a known or suspected arrhythmogenic right ventricular cardiomyopathy (ARVC). Several abnormalities have been found and described by CMR and at present this diagnostic tool is considered very important for the diagnosis. However, the diagnosis of ARVC relies upon the fulfillment of both clinical and functional criteria and CMR can provide several but not all the information useful for the diagnosis. Furthermore, some findings such as evidence of right ventricular epicardial fat, once considered a peculiar marker of ARVC, have been shown to possess a low specificity. This document was prepared by representatives of the three Italian official Organizations involved in CMR. Its main scope is to highlight the problems encountered when studying patients with suspected ARVC at CMR, to indicate the basic technical equipment needed, to recommend a proper imaging protocol and to offer a consensus on the main features relevant for the diagnosis.

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Background

Arrhythmogenic right ventricular cardiomyopathy (ARVC) is a cardiac disease recently included among the cardiomyopathies characterized by either fatty or fibro-fatty replacement of the normal right ventricular myocardium[1]. ARVC patients are generally young male individuals showing a variety of ventricular arrhythmias that may be severe and occasionally cause sudden death, particularly during physical activity[2-4]. Less frequently ARVC is characterized by progressive heart failure due to right ventricular dysfunction. ARVC shows a variable degree of genetic inheritance and is observed more frequently in specific geographical areas. The diagnosis is based on internationally accepted criteria that are both clinical and instrumental[5].

In the past few years cardiovascular magnetic resonance imaging (CMR) has emerged as an important diagnostic tool in ARVC[6-14]. CMR is the best diagnostic technique for the evaluation of both the anatomy and function of the right ventricle and therefore it has been used since its early introduction to image ARVC patients[6]. Due to the ability of CMR to detect fatty tissue, it has been suggested that this technique could permit a diagnosis of ARVC on the basis of the recognition of the histopathological marker of this disease. Therefore, a growing number of subjects with a clinical suspicion of ARVC were scanned with the aim of documenting fat. Several theoretical and practical considerations challenge this issue. Indeed, fat may be identified in a variety of conditions including normal subjects[15-17] and technical constraints do not allow the detection of small fat deposits. Therefore, the detection of fat by means of CMR for the diagnosis of ARVC is today considered less important than in the past. Other abnormal morphologic and functional aspects of the right ventricle in ARVC may be precisely demonstrated; very frequently these abnormalities are subtle and seen exclusively at CMR. Specific diagnostic criteria, and profound knowledge of the subject are requested: unless these aspects are known in depth, a large number of ei-

ther false positive or missed diagnoses is to be expected.

This document has been prepared by representatives of the three Italian official Organizations involved in CMR. Its main scope is to highlight the problems encountered when studying patients with suspected ARVC by means of CMR, to indicate the basic technical equipment needed, to recommend a proper imaging protocol and to offer a consensus on the main diagnostic features that should be looked for.

Definition

In the classification of the World Health Organization Report of Cardiomyopathies issued in 1996, ARVC is described as a new entity of unknown origin. It is characterized by fibro-adipose substitution of the myocardium mainly involving the right ventricle. ARVC patients have frequent severe ventricular arrhythmias that can cause sudden death[18-20]: having been demonstrated in up to 20% of deaths in individuals < 30 years of age, this disease represents an important cause of mortality[3]. Recently, ARVC has been shown to be the most common cause of exercise-related sudden death among young athletes in Italy[4]. ARVC is considered a progressive disease potentially leading to heart failure and death after a variable number of years. The right ventricle is the cardiac site preferentially affected but the left ventricle may also be involved, especially in severe cases[21].

Diagnosis of arrhythmogenic right ventricular cardiomyopathy

There are no definite single elements allowing the diagnosis of ARVC; the presence of ARVC may be taken into consideration once other causes of right ventricular disease have been ruled out. The diagnosis relies upon the fulfillment of well-defined criteria[5]. These include clinical and electrocardiographic features as well as the pattern of ventricular contraction and/or the results of endomyocardial biopsy. The criteria are listed in table I. On the basis of this classification, the diagnosis of ARVC is set when two major criteria, or one major plus two minor criteria, or four minor criteria from different groups are present.

Etiology and pathogenesis

Several hypotheses to explain the causes and pathogenesis of ARVC have been put forward[18,19]. The first considers ARVC as a developmental abnormality (i.e. dysplasia) of the right ventricular myocardium. A second one postulates the presence of a degenerative process promoted by progressive myocardial cell death due to apoptosis[22,23]. Yet another hypothesis suggests that one or more inflammatory processes may trigger some changes that eventually determine ARVC and its manifestations. Both inflammatory lymphocytic infiltrates and signs of viral infection[24] have been demonstrated in the myocardium of ARVC patients[25,26]. It should be pointed out, however, that lymphocytic infiltrates may be a response to spontaneous myocardial death. Thus, there is no evidence to support the theory that inflammation is a primary cause, rather than a reaction to apoptosis[27]. Today, there is general consensus about considering ARVC as the result of a generic predisposition and/or susceptibility to viral infection followed by an immune reaction and/or a genetically determined spontaneous cell death. Indeed, clinical genetic studies have indicated that the disease may be autosomal-dominantly inherited with an age-related and variable penetrance[28], although only a small number of mutations have been identified[29-32].

Table I. Criteria for the diagnosis of right ventricular cardiomyopathy.

I. Global or regional dysfunction and structural alterations
Major
Severe dilation and reduction of the RV ejection fraction with no (or only mild) LV impairment.
Localized RV aneurysms (akinetic or dyskinetic areas with diastolic bulging).
Severe segmental dilation of the right ventricle.
Minor
Mild global RV dilation or ejection fraction reduction with a normal left ventricle.
Mild segmental dilation of the right ventricle.
Regional RV hypokinesia.
II. Tissue characterization of walls
Major
Fibro-fatty replacement of the myocardium on endomyocardial biopsy.
III. Repolarization abnormalities
Minor
Inverted T waves in right precordial leads (V_2 and V_3) (subjects aged > 12 years, in the absence of right bundle branch block).
IV. Depolarization/conduction abnormalities
Major
Epsilon waves or localized prolongation (≥ 110 ms) of the QRS complex in right precordial leads (V_1 to V_3).
Minor
Late potentials (signal-averaged ECG).
V. Arrhythmia
Minor
Left bundle branch block-type ventricular tachycardia (sustained and non-sustained) (ECG, Holter, exercise testing).
Frequent ventricular extrasystoles (> 1000/24 hours) (Holter).
VI. Family history
Major
Familial disease confirmed at necropsy or surgery.
Minor
Family history of premature sudden death (≤ 35 years) due to suspected RV dysplasia.
Family history (clinical diagnosis based on the present criteria).

ECG = electrocardiogram; LV = left ventricular; RV = right ventricular. From McKenna et al.[5], modified.

Pathology

The pathological diagnosis of ARVC is based upon the evidence of a transmural fatty or fibro-fatty replacement of the right ventricular myocardium in the absence of other cardiac and non-cardiac causes of death[33,34]. Fatty or fibro-fatty replacement is observed mainly at the infundibulum and apex, and in the postero-inferior wall in the so-called "triangle of dysplasia". Aneurysmal dilation or bulging, scars and wall thinning may also be found. Ventricular dilation is usually observed. Two main pathologic presentations of ARVC have been described: a pure adipose form and a fibro-fatty form[16]. This distinction has been challenged because the isolated fatty form seems to have peculiar features that suggest a totally different disease. In typical ARVC, the right ventricular wall is replaced by fibro-fatty tissue. Fibro-fatty substitution usually begins in the subepicardium or mid-mural layers of the right ventricle and progresses towards the endocardium with replacement of myocytes and thinning of the wall. Other distinct aspects include replacement fibrosis and myocyte atrophy, which may occur in virtually any area of the right ventricle thus contributing to myocardial thinning. As already mentioned, lymphocytes are frequently found at histology[21,27]. It is possible that after a variable period of activity, characterized by an inflammatory process, apoptosis and necrosis with fatty substitution of the diseased right ventricle, the disease might stop and scar formation ensues.

Clinical features

ARVC may have several different presentations[18,19]. Palpitations, syncope, congestive heart failure or sudden death may be the first sign of the disease. Ventricular arrhythmias are usually present in ARVC and may vary in frequency and severity[35-37]. In many cases ventricular ectopic beats are frequent (> 1000/24 hours at Holter recordings) and very often both non-sustained and/or sustained ventricular tachycardia may be detected. Arrhythmias occur frequently during exercise and daytime. Ventricular arrhythmias usually have a left bundle branch block (LBBB) morphology as they originate from the right ventricle. This is not a specific feature of ARVC as many diseases may determine LBBB ventricular arrhythmias (i.e. coronary artery disease, idiopathic dilated cardiomyopathy, or a right ventricular scar after surgical repair of congenital heart disease). Several electrocardiographic abnormalities may also be associated: inverted T waves in right precordial leads (V_2 and V_3), epsilon waves (up to 30% of the patients) or localized prolongation (> 110 ms) of the QRS complex in right precordial leads (V_1) in the absence of right bundle branch block. The signal-averaged electrocardiogram is usually abnormal, reflecting the presence of areas of slow conduction, a prerequisite for reentrant arrhythmias. Ventricular arrhythmias are typically evoked by adrenergic stimulation as exercise testing provokes them in 50-60% of ARVC patients and isoproterenol administration may induce ventricular tachycardia in 85% of such individuals[38,39].

Some kind of inheritance of the disease can be demonstrated in as many as 30-50% of patients[18-20]. The disease is inherited as a dominant autosomic character with different degrees of clinical expression. The prevalence of ARVC in the general population is about 1:5000 subjects. It is usually observed in young (< 40 years) adult men (about 80% of all the cases). The diagnosis should be always considered in young people exhibiting syncope or ventricular tachycardia or sudden death. In the United States ARVC accounts for 5% of sudden deaths in men < 65 years old and for 3-4% of sudden death during sports activity. In the Veneto Region (Italy), ARVC is the most common cause of arrhythmic death in men < 35 years old and the most common cause of death among Italian athletes. The annual mortality for ARVC is considered to be 3% without treatment and 1% when taking antiarrhythmic drugs. The cause of death seems to be the increase in the heart rate of a ventricular tachycardia degenerating to ventricular fibrillation.

It is not clear whether ARVC is a progressive disease and the available information on this issue is limited. In a recent study on families of ARVC patients the prognosis was very good in terms of mortality despite an apparent progression of the disease[40]. In spite of the fact that the high variability of both the clinical and morpho-functional aspects of ARVC may indicate a progression of the disease, definite proof of this is still lacking. Currently, an international registry is being developed that should provide answers to many questions about the natural history of ARVC[41].

Imaging tools for the recognition of arrhythmogenic right ventricular cardiomyopathy

Several imaging techniques (echocardiography, angiography, myocardial perfusion scintigraphy, computed tomography and CMR) may detect right ventricular structural and functional abnormalities in ARVC patients. These range from small ventricular wall aneurysms with localized wall motion abnormalities to marked chamber dilation with diffuse hypokinesia.

In clinical practice, echocardiography is the front-line imaging technique[42-44]; its sensitivity and specificity are low particularly in patients with suboptimal image quality and limited abnormalities. Although ventricular alterations can go undetected even when the quality of the examination is satisfactory, their demonstration in the absence of a causative mechanism becomes diagnostically important. Echocardiography is thus particularly useful for the screening of patients with suspected ARVC and best performs in case of severe disease.

Right ventricular angiography can detect several abnormalities[45-47]: diffuse or localized dilations, diastolic bulgings, wall motion abnormalities and other less specific signs have been described. Angiography, however, is nowadays seldom performed owing to its invasive nature, the need of contrast media and X-ray exposure.

The demonstration of fat at myocardial biopsy is considered specific but not sensitive since biopsy results depend on the ability to collect significant samples, and small, localized fibro-fatty areas of substitution may be missed. Moreover, biopsy may be safely performed only at the interventricular septum, which is rarely involved by the disease, whereas biopsy of the right ventricular free wall may unfortunately be complicated by perforation of the heart and cardiac tamponade. In any case, ARVC fibro-fatty deposits must be differentiated from occasionally occurring islands of adipose tissue which may be found even in a normal heart. It can be seen in up to 15% of normal subjects[16] and in more than 50% of normal elderly people[17]. Pathologic conditions which have been associated with fatty changes of the right ventricle include chronic alcohol intake and some inherited myopathies.

A sensitivity of 67% and a specificity of 92% for ARVC have been found when the biopsy is obtained from the right ventricular free wall[15]. A percentage of fat > 3% and of fibrous tissue > 40% with amounts of myocytes < 45% usually afford for a clear cut distinction between ARVC and normal hearts or dilated cardiomyopathy[48].

Electron beam computed tomography and multislice computed tomography have also been used to detect and evaluate ARVC[49,50]. These techniques may provide direct evidence of fatty replacement, kinetic alterations and chamber dilation. Compared to electron beam computed tomography, multislice computed tomography may allow for higher spatial resolution and reduced motion artifacts. These techniques have not been widely applied so that a sound knowledge about their diagnostic accuracy is still lacking. It should be pointed out however that both techniques require the use of contrast media and X-ray exposure thus being suboptimal for follow-up purposes.

Cardiovascular magnetic resonance and cardiovascular disease

CMR represents a powerful non-invasive diagnostic tool in cardiovascular medicine[51,52]. Since its introduction, this technique proved its efficacy for evaluating the heart and its surrounding structures with high spatial resolution and natural contrast. Cardiovascular structures can be imaged with a spatial resolution up to $0.5 \times 0.5 \times 1.5$ mm. Cine-loop images with a temporal resolution of 20-40 frames/s are obtainable thus permitting evaluation of the motion of the cardiac valves, of wall thickening, of the ventricular volumes and their changes during the cardiac cycle. As the magnetic properties of fluids are influenced by movement, the flow can be described in terms of its absolute velocity thus allowing measurement of the cardiac output, shunts, pressure gradients, etc. Finally, CMR also has the potential of characterizing different tissues by taking advantage of their different magnetic properties.

Cardiovascular magnetic resonance and the right ventricle

The right ventricle is the most challenging section of the heart for all imaging techniques. Right heart angiography, radionuclide methods and echocardiography have all been used to evaluate right ventricular chamber size, dynamics and morphology. Angiographic techniques require cardiac catheterization, contrast media and significant X-ray exposure. No information can be obtained on the ventricular wall, and geometric assumptions for volume calculations are needed. Radionuclide angiography can easily measure the right ventricular volume. However, due to its low spatial resolution even with gated single photon emission computed tomography techniques, little information may be obtained both on the chamber morphology and on the wall structure.

Echocardiography is currently the method more extensively used to evaluate both the right ventricular anatomy and function. However, volume determinations are difficult and precise measurements cannot be obtained. In adults, a complete visualization of the right ventricle is seldom possible and wall imaging is intrinsically poor. Although image quality and thus clinical information may be improved by a transesophageal approach, the wall structure remains unexplorable.

CMR provides excellent images of the right ventricle, and may be used to measure the right ventricular volume and function[53-55]; the same applies to the ventricular mass and wall thickening. Most importantly CMR has the potential of revealing fibro-fatty myocardial substitution. CMR performances are so good that this technique is nowadays considered the gold standard for right ventricular imaging.

Cardiovascular magnetic resonance and arrhythmogenic right ventricular cardiomyopathy

Since its early applications CMR has been used to image ARVC patients. The potential of CMR for the diagnosis of ARVC was first described in 1987[6]. CMR could show dilation of the right ventricular outflow tract, thinning of the wall, diastolic bulging and myocardial fatty substitution of the right and left ventricular free walls (Figs. 1-4). Subsequently, many authors[7-14] confirmed its diagnostic potential on large series of ARVC patients.

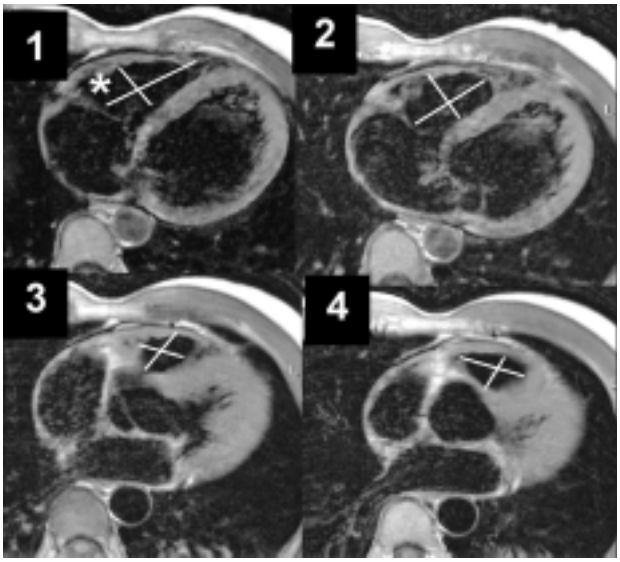

Figure 1. *Arrhythmogenic right ventricular cardiomyopathy patient. Transversal scan. Spin-echo-based sequence. The right ventricle is enlarged, particularly in the inflow part.* White lines *show where and how the right ventricular dimensions may be measured.* (*) *identifies the right ventricular inflow tract.*

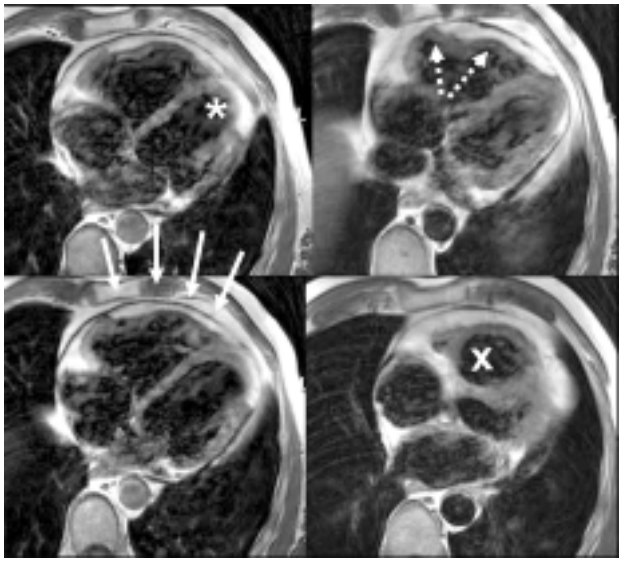

Figure 2. *Arrhythmogenic right ventricular cardiomyopathy patient. The right ventricle is grossly enlarged in all its parts, including the infundibulum (X). The* dotted arrows *highlight some right ventricular wall aneurysms. The right ventricular wall shows a marked increase in signal intensity compatible with intramyocardial right ventricular fat on the epicardial side* (continuous line arrows). *Even the left ventricle is involved* (*).

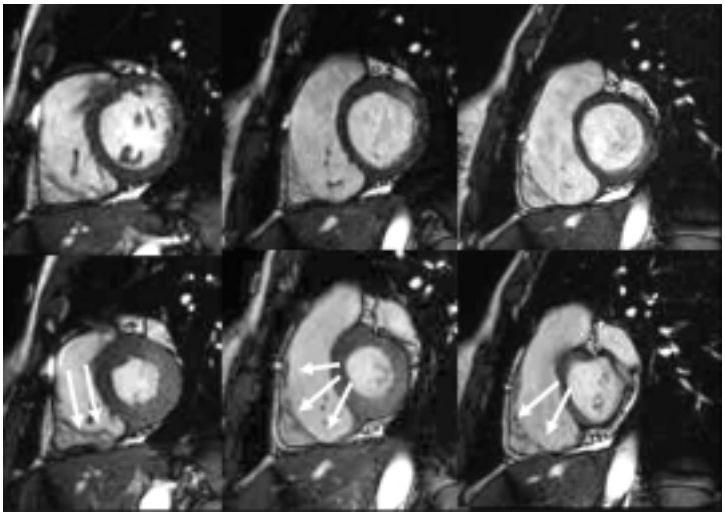

Figure 3. *Arrhythmogenic right ventricular cardiomyopathy patient. Steady-state free precession breath-hold cine-cardiovascular magnetic resonance series on the short-axis view of the left ventricle. The right ventricle is shown in diastole* (upper images) *and systole* (lower images) *at three different levels. The* arrows *show the decreased-absent wall motion of the right ventricle, particularly of the inferior and lateral wall.*

CMR proved to be able to precisely identify all morphological and functional abnormalities fulfilling the criteria listed in the international classification (segmental or diffuse chamber dilation; diastolic bulgings and aneurysms; wall thinning; wall motion abnormalities; fibro-fatty replacement of the myocardium).

One should note however that in relatives of patients with ARVC (a group at high risk of having ARVC themselves) many very subtle right ventricular alterations may also be found. These subjects are to be considered high-risk patients although not showing the main features of ARVC. This observation suggests that the currently available criteria for the diagnosis of ARVC may be too restrictive and suboptimal for the detection even of high-risk patients[56].

The problem of fat demonstration by cardiovascular magnetic resonance

The CMR potential for demonstrating fat infiltration non-invasively raised the enthusiastic attention of the medical community so that many groups diagnosed ARVC in an ever-increasing number of subjects. Very

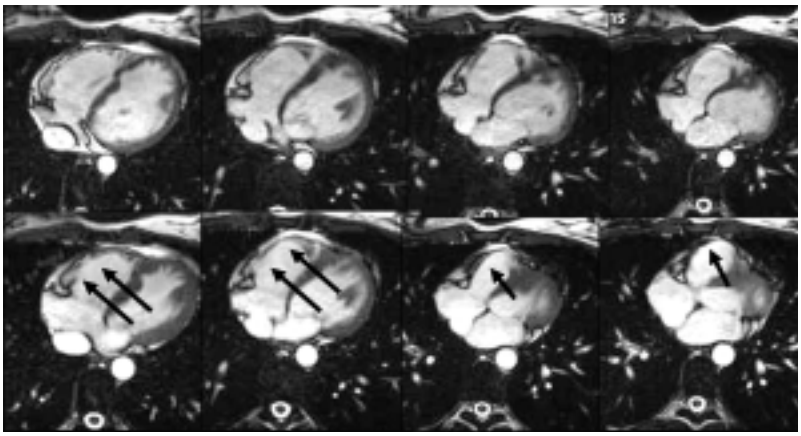

Figure 4. *Arrhythmogenic right ventricular cardiomyopathy patient. Steady-state free precession breath-hold cine-cardiovascular magnetic resonance series on the transversal plane of the heart. The right ventricle is shown in diastole* (upper images) *and systole* (lower images) *at four different levels. The* arrows *show the decreased-absent wall motion of the right ventricle.*

soon, however, some criticism arose that challenged this apparently happy marriage between CMR and ARVC[57]. It was in fact demonstrated that intramyocardial fat could be observed both in normal subjects and in patients with other diseases. Moreover, some ARVC patients do have a mixed fibro-fatty structural abnormality and fibrous tissue may even be more abundant than fat.

Several technical issues negatively affecting CMR results must always be kept in mind. First of all, the precise localization of fat is not straightforward as the spatial resolution may be insufficient for the distinction between a substituted right ventricular epicardium and a normal subepicardial fat layer. As adjunct, motion artifacts and degraded image quality resulting from poor gating when ectopic beats occur, do impair imaging results by the more commonly used T_1-weighted image sequences.

Nowadays, therefore, the isolated detection of fat at CMR should be interpreted with caution and considered as potentially misleading. Right ventricular wall thinning, motion abnormalities and regional or global dilation should be considered much more significant for the diagnosis; an area of increased signal intensity compatible with myocardial fatty substitution should be regarded as an ancillary sign rather than as the hallmark of this disease (Fig. 2).

Cardiovascular magnetic resonance and the so-called "minor forms" of arrhythmogenic right ventricular cardiomyopathy

A large proportion of patients exhibiting ventricular arrhythmias with a LBBB morphology do not show evidence of ARVC at echocardiography. The majority of those who were subsequently submitted to a CMR exam did not have ARVC or at least did not show the most severe aspects of the disease; nevertheless, various alterations could be found, the most frequent being right ventricular wall motion abnormalities.

White et al.[58] investigated 53 patients with evidence of a ventricular arrhythmia with a LBBB morphology but without echocardiographic evidence of ARVC. CMR demonstrated fixed wall thinning in 84% of cases, fatty replacement in 25%, and reduced wall thickening or motion in 97% suggesting that ARVC and idiopathic right ventricular outflow tract arrhythmias might represent clinical manifestations of a wide spectrum disease. Similarly, Proclemer et al.[59] reported wider dimensions of the right ventricular outflow tract in 19 patients with monomorphic (LBBB) extrasystoles compared with a control group. Wall motion and morphological abnormalities were present in 84% of cases. Gaita et al.[60] reported the long-term follow-up of 11 patients (mean 15 years, range 12 to 20 years) with right ventricular monomorphic LBBB extrasystoles. CMR showed right ventricular abnormalities in 73% of the patients, but no patient died of sudden death or developed ARVC; two thirds of the patients were asymptomatic and in 51% of them the ectopy disappeared.

Another group of patients not having ARVC but clinically characterized by a ventricular tachycardia with a LBBB morphology and previously regarded as having a normal cardiac anatomy and function are those with right ventricular outflow tract tachycardia. These patients are considered as having a benign condition even though sudden death may occur. Using cine-CMR, Carlson et al.[61] reported a high rate (95%) of cardiac abnormalities; fixed focal wall thinning, a regionally decreased wall thickness and an abnormal wall motion were seen in 22. Globits et al.[62] studied 20 patients who underwent radiofrequency catheter ablation for symptomatic right ventricular outflow tract tachycardia; CMR revealed structural abnormalities including focal wall thinning, right ventricular outflow tract dilation or saccular aneurysms in the right ventricular

outflow tract which were significantly associated with the site of origin of the tachycardia.

The available data do not help to understand whether right ventricular outflow tract tachycardia patients do have a form of ARVC[63] or, as some authors suggest[36,37], a different disease. Although when studying patients with right ventricular outflow tract tachycardia several findings commonly seen in ARVC patients can indeed be shown, these alterations are not as evident as in ARVC.

Technical aspects of cardiovascular magnetic resonance

Spin-echo images are used to evaluate the right ventricular wall: conventional or multi-shot fast techniques may be employed. Dedicated cardiac coils may be used to increase spatial resolution; they are very useful whenever fat shows up as areas of increased signal intensity within the outer right ventricular anterior wall and when it is difficult to distinguish it from the subepicardial fat.

The functional evaluation of the right ventricle is accomplished by gradient-echo images that may be acquired in a few seconds and allow evaluation of both the wall thickening and chamber volume changes throughout the cardiac cycle. Breath-hold fast-gradient echo or steady-state free precession sequences (if available) may be used. The stroke volume and ejection fraction may be measured: diseased segments may show variable degrees of wall motion abnormalities (hypo-/a-/dyskinesia) and/or small aneurysmal dilations and/or focal wall thinning.

To entirely evaluate the right ventricle, the chamber should be imaged in both the long- and short-axis views, so as to avoid missing functional alterations of the inferior wall.

Ventricular extrasystoles are a common finding in these patients: the occurrence of many of them and particularly the presence of a bigeminal rhythm may so greatly impair the results of CMR scanning as to necessitate repetition of the exam with the patient on antiarrhythmic therapy.

Recommendations

The most important concept to keep in mind when using CMR to evaluate a potential ARVC patient is that we should collect those dimensional, morphological and functional data that meet the criteria established by the European Society of Cardiology Committee (Table I).

The majority of CMR studies on ARVC have been performed by a variety of scanners with different field strength: only those with a field ≥ 0.5 are recommended.

In view of the importance of collecting anatomic details, spin-echo T_1-weighted images should initially be obtained in the transaxial plane to image the right ventricular free wall and outflow tract; images in the short-axis plane to evaluate the inferior wall and the subtricuspid area of the right ventricle should then be acquired. Significant fat infiltrations should be looked for as they may be detected when they are sufficiently large; artifacts due to respiratory movements, and insufficient spatial resolution may however prevent the detection of small infiltrations.

As a second step, we consider it mandatory to explore the right ventricular wall motion as accurately as possible. This can be achieved by a multislice gradient-echo cine series (usually 5-7 non contiguous 8 mm thick slices) both in the axial and in the short-axis planes (Fig. 5). The right ventricular free wall and outflow tract wall motion can be evaluated from transaxial images: short-axis images are needed for the functional evaluation of the inferior wall of the right ventricle, particularly in the subtricuspid area. When available, the newly developed steady-state free precession imaging technique is recommended as it yields very high quality cine series.

The Panel strongly recommends the above sequence protocol for CMR evaluation of ARVC (Table II). Other, more sophisticated, imaging sequences are not considered as mandatory by this Committee. It must be stressed again that the demonstration of fat by CMR, although possible, may be difficult and, if an isolated

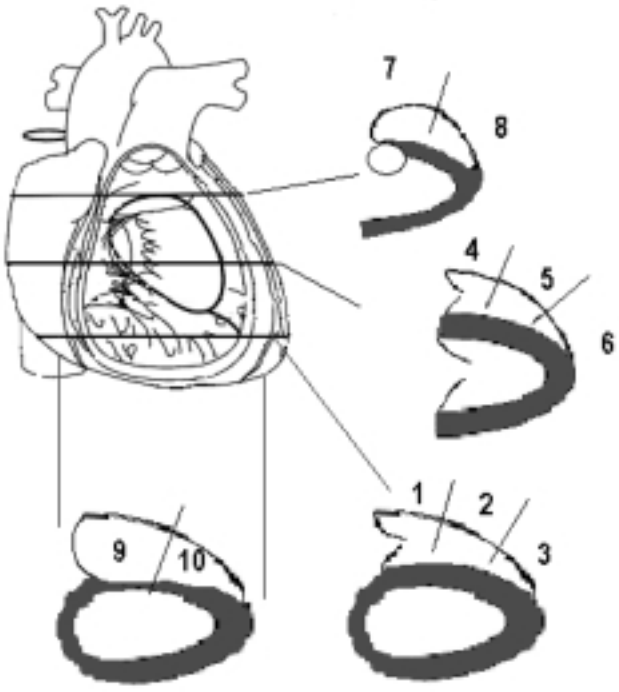

Figure 5. *Schematic proposed segmentation of the right ventricle. 1, 2 and 3 are the lower and 4, 5 and 6 are the basal, mid and apical inflow segments; 7 and 8 are the outflow tract segments; 9 and 10 are the right ventricular inferior wall segments. All these segments should be examined.*

Table II. Imaging protocol for the evaluation of patients with suspected arrhythmogenic right ventricular cardiomyopathy.

	Scout scan to localize the heart within the thorax			
A	Spin-echo or IR multi-shot fast spin-echo	Transversal scan	9-15 slices	8-10 mm thick
B	Spin-echo or IR multi-shot fast spin-echo	Short-axis scan	6-12 slices	8-10 mm thick
C	Fast gradient-echo or steady-state free precession	Transversal scan or oblique 4-chamber view	(5-9) slices At least 20 cardiac phases for each slice	8-10 mm thick
D	Fast gradient-echo or steady-state free precession	Short-axis scan	(5-9) slices At least 20 cardiac phases for each slice	8-10 mm thick contiguous slices for volumetric acquisition

IR = inversion recovery.

finding, neither specific nor relevant for the diagnosis. When true fatty substitution is present, wall motion abnormalities, dilation of the right ventricle and variable size aneurysms are constantly present; in the absence of such accompanying features, the demonstration of fat may be a source of false positive diagnoses.

Report of the examination

An important issue is the report of the examination. An appropriate report should include all the available information, both anatomical and functional, that may help in the diagnostic work-up of ARVC. For this reason it is important to describe the anatomy of the right ventricle including its dimensions. It is recommended that in the written report the diastolic dimensions of the right ventricle should be indicated. Measurements should be taken of the inflow, outflow and infundibular tracts of the right ventricle (Figs. 1 and 5). Figure 5 is a proposal of subdivision of the right ventricle in 10 segments. Segments 9 and 10 are the inferior wall segments; the remaining 8 refer to the inflow and outflow tracts and infundibulum of the right ventricle. There are currently no detailed studies describing the normal right ventricular diameters. Nevertheless, it is important to take these measurements in order to obtain some reference values in each patient to which to compare subsequent examinations. Linear measurements should be taken in the most diastolic image of the right ventricle. It should be stressed however that normal linear dimensions for the right ventricle are not available and these measures are only relevant for a detailed description of the right ventricle and for follow-up purposes.

Some studies have provided the normal values for the right ventricular volume. In table III[64-68] the main data available from the literature are shown and may be used as normal reference values. As clearly shown, the right ventricular volume may vary significantly; however, values > 140 ml or > 75 ml/m^2 are clearly abnormal.

It is also recommended that the right ventricular wall motion as it is related to the global and regional contraction also be described. The proposed schematic right ventricular segmentation may help in describing wall motion segmental abnormalities both with regard to their location and extension.

Keeping in mind that abnormal fatty deposition *per se* has very little specificity with regard to the presence of ARVC, its importance is therefore less than once expected. Areas of strong signal intensity involving the ventricular walls should be described all the same. An effort should be made not to stress the presence of such areas when these are small, or located either along the atrioventricular junction or the interventricular groove in the absence of other more specific signs. In this case a suggestion that abnormal fatty deposition might be present can be given. It would also be advisable to report on the absence (or the presence) of other conditions (such as atrial septal defect, Ebstein anomaly, pulmonary valve stenosis) which may alter right ventricular geometry and dimensions.

Table III. Normal right ventricular dimensions.

	EDV (ml)	ESV (ml)	EDVI (ml/m^2)	ESVI (ml/m^2)
Sechtem et al.[64]	111 ± 22	40 ± 13	63 ± 9	22 ± 6
Helbing et al.[65]*	92 ± 25	27 ± 9	92 ± 25	27 ± 9
Mogelvang et al.[66]	–	–	90	46
Lorenz et al.[67]	138 ± 40	54 ± 21	–	–
Sandstede et al.[68]	115 ± 31	43 ± 19	–	–

EDV = end-diastolic volume; EDVI = end-diastolic volume index; ESV = end-systolic volume; ESVI = end-systolic volume index.
* measurements obtained in normal children.

Conclusions

Patients referred for suspected ARVC represent a heterogeneous group of individuals and, besides ARVC patients, include normal subjects, patients with other cardiac diseases, and many subjects whose abnormal features of the right side of the heart do not fit any definite diagnosis. The latter are frequently considered as having "minor forms" of ARVC; this term implies both a link with ARVC as well as a possible evolution toward ARVC that have never been consistently demonstrated; therefore this term is not recommended. The Panel suggests that these subjects be simply described as having a right ventricular disease, which does not imply a link with ARVC.

The diagnosis of ARVC represents a major challenge whatever the diagnostic tool employed. CMR is nowadays considered the gold standard for the diagnosis of ARVC. However, it is now well established that ARVC may only be diagnosed by using internationally accepted criteria many of which are based on the clinical presentation and on the history of the patient. Therefore, CMR should not be used to diagnose the disease but should be viewed as the best available technique to obtain morphologic and functional information of the right ventricle, thus potentially providing some findings necessary for the diagnosis. It should also be stressed the fact that when strict recommendations in performing and interpreting the examination are not used, even centers of excellence may have severe difficulties in providing the diagnosis[69]. Therefore, it is particularly important to use a well-defined imaging protocol, an updated scanner and imaging sequences, and also to provide precise and possibly quantitative information.

Young individuals exhibiting LBBB ventricular arrhythmias represent the vast majority of subjects referred to either the cardiologist or the radiologist for CMR evaluation. Sometimes an enlarged right ventricle is present with or without other echocardiographic signs. In a few cases, ventricular tachycardia (either non-sustained or sustained) has been documented, or patients may have previously necessitated cardiopulmonary resuscitation because of ventricular fibrillation. Another group of potential candidates for CMR to rule out or confirm ARVC are relatives of ARVC patients. The most difficult group to evaluate consists of subjects with ventricular arrhythmias and apparently normal hearts who are involved in sports activity; for these, in view of the strenuous physical activity they have to face, a definite diagnosis should be sought at all costs; this group also represents an intriguing health policy issue.

Due to the growing reliance/interest of the cardiologist upon CMR, expectations often go beyond reality. Quite often, the clinician attributes to CMR a diagnostic role that alone it cannot possess; nonetheless, CMR data are many and often unique. The cardiology and radiology communities should be fully aware of the important legal, medical, and psychological issues raised by either a missed diagnosis or by a false positive one.

CMR examiners should not be under pressure to provide a diagnosis at all costs. Near-normal findings must be interpreted and reported with a high degree of caution as they may generate false positive diagnoses simply because referring physicians may be strongly motivated in finding something abnormal.

CMR must be considered as the best imaging technique for the evaluation of the right ventricle both anatomically and functionally. It may provide those diagnostic elements that are used to meet the criteria suggested by the European Society of Cardiology Committee on ARVC and that cannot be obtained by other means.

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