REVIEW

The Current Role of Cardiovascular Magnetic Resonance Imaging According to European Society of Cardiology Guidelines and Statements

(Third part)

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PART III

ARRHYTHMIAS, SYNCOPE, SUDDEN CARDIAC DEATH AND DEVICES

2019 ESC Guidelines for the management of patients with supraventricular tachycardia[1]

Tachycardia-induced cardiomyopathy is one of the very few reversible causes of heart failure (HF) and DCM (dilated cardiomyopathy), and should be considered in any patient with new onset of left ventricular (LV) dysfunction. In the presence of persistent or frequent tachycardia, or frequent premature ventricular contractions, a high index of suspicion should be maintained. The diagnosis is established by excluding other causes of cardiomyopathy, and demonstrating recovery of LV function after eradication of the arrhythmia or control of the ventricular rate. In patients with suspected tachycardia-induced cardiomyopathy, CMR is advisable to exclude intrinsic structural change.

2018 ESC Guidelines for the diagnosis and management of syncope[2]

CT or CMR should be considered in selected patients presenting with syncope of suspected cardiac structural origin when echocardiography is not diagnostic.

Unexplained syncope in patients at high risk of sudden cardiac death (SCD) due to arrhythmogenic right ventricular cardiomyopathy (ARVC): although limited and diverse, current data suggest that unexplained syncope is a marker of arrhythmic risk in patients with ARVC. The decision to implant an implantable cardioverter-defibrillator (ICD) should take into account the other known risk factors for arrhythmic events: frequent non-sustained VT, family history of premature sudden death, extensive right ventricular disease, marked QRS prolongation, late gadolinium enhancement (LGE) on CMR (including LV involvement), LV dysfunction, and VT induction during electrophysiological study.

2015 ESC Guidelines for the management of patients with ventricular arrhythmias and the prevention of sudden cardiac death[3]

The diagnostic approach for family members of sudden unexplained death syndrome or sudden arrhythmic death syndrome victims includes: history taking and physical examination, ECG tests, cardiac imaging (two-dimensional echocardiography and/or CMR) and genetic testing.

CMR or CT should be considered in patients with ventricular arrhythmias when echocardiography does not provide accurate assessment of LV and right ventricular (RV) function and/or evaluation of structural changes (class IIa recommendation, level of evidence B).

The diagnostic workup in patients presenting with sustained ventricular tachycardia (VT) or ventricular fibrillation (VF) includes CMR for evaluation of cardiovascular diseases both in the presence of a transient cause and as further test in suspected heart disease, its need being guided by the initial assessment (ECG,

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echocardiogram, history and family history).

In patients with scar-related heart disease presenting with VT or VF, pre-procedural CMR imaging may facilitate non-invasive identification of the arrhythmic substrate in patients with a history of MI or in patients presenting with epicardial VT.

In patients with documented symptomatic sustained VT of unclear etiology, myocarditis should also be suspected and a CMR scan may reveal abnormal fibrotic myocardial tissue, frequently located in subepicardial and intramural regions. Demonstration of persistent myocardial inflammatory infiltrates by immunohistological evidence and/or abnormal localized fibrosis by CMR after acute myocarditis may be considered as an additional indicator of increased risk of SCD in inflammatory heart disease (class IIb recommendation, level of evidence C).

Regarding prevention of SCD in athletes, upon identification of ECG abnormalities suggestive of structural heart disease, echocardiography and/or CMR imaging is recommended (class I recommendation, level of evidence C).

2013 ESC Guidelines on cardiac pacing and cardiac resynchronization therapy[4]

MRI in patients with implanted cardiac devices. Since it is estimated that, after implantation, up to 75% of patients with pace-makers (PM) develop an indication for MRI examination owing to medical co-morbidities, this Task Force believes it is necessary to provide recommendations on how to perform an MRI examination safely in patients with conventional devices. Potential adverse effects of MRI on implanted cardiac devices include: radiofrequency-induced heating of the lead tips, pacing inhibition/dysfunction, asynchronous pacing with the possibility of induction of atrial or ventricular tachyarrhythmias, transient reed switch activation, change or loss of programmed data and changes in capture threshold.

When MRI is necessary for clinical management of serious diseases, the benefit of MRI might outweigh the risk of performing MRI. Alternative imaging techniques have to be considered. A consultation with the electrophysiology specialist is warranted. No information exists for MRI performed at >1.5 T, even for MRI compatible devices. This possibility needs further evaluation.

In patients with conventional cardiac devices, MRI at 1.5 T can be performed with a low risk of complications if appropriate precautions are taken (class IIb recommendation, level of evidence B).

In patients with MR-conditional PM systems, MRI at 1.5 T can be done safely following manufacturer instructions (class IIa recommendation, level of evidence B).

Suggestions for conventional device programming when MRI is required include: (i) because changes in device variables and programming may occur, monitoring by qualified personnel during MRI is essential; (ii) exclude patients with leads that have not matured (< 6 weeks since implantation, during which the leads are prone to spontaneous dislodgement) and those with epicardial and abandoned leads (which are prone to heating); (iii) programme an asynchronous pacing mode in PM-dependent patients to avoid inappropriate inhibition of pacing due to detection of electromagnetic interference; (iv) in contrast, use an inhibited pacing mode for patients without PM dependence, to avoid inappropriate pacing due to tracking of electromagnetic interference; (v) deactivate other pacing functions (magnet, rate, noise, premature ventriculat contratcions, ventricular sense, atrial fibrillation response) in order to ensure that sensing of electromagnetic interference does not lead to unwarranted pacing; (vi) deactivate tachyarrhythmia monitoring and therapies to avoid delivery of unwarranted therapies; (vii) re-programme the device immediately after the MRI examination.

For MRI-conditional devices the basic elements are identical to conventional cardiac devices and programming as described in (iii), (iv), (v) and (vi) is automatically performed by an external physician-activated device.

VALVULAR HEART DISEASE

2017 ESC/EACTS Guidelines for the management of valvular heart disease[5]

Following adequate clinical evaluation, echocardiography is the key technique used to confirm the diagnosis of valvular heart disease as well as to assess its severity and prognosis.

In patients with inadequate echocardiographic quality or discrepant results, CMR should be used to assess the severity of valvular lesions, particularly regurgitant lesions, and to assess ventricular volumes, systolic function, abnormalities of the ascending aorta and myocardial fibrosis. CMR is the reference method for the evaluation of RV volumes and function and is therefore particularly useful to evaluate the consequences of tricuspid regurgitation.

In aortic regurgitation CMR should be used to quantify the regurgitant fraction when echocardiographic measurements are equivocal. If the ascending aorta is dilated (>40mm) it is recommended to perform CT or CMR. Follow-up assessment of dilated ascending aorta should be performed using echocardiography and/or CMR. Any increase aortic dimension > 3mm should be validated by CT angiography/CMR and compared to baseline data. Indication for surgery should preferably be based on CT measurements.

In aortic stenosis CT and CMR provide additional information on the dimensions and geometry of the aortic root and ascending aorta and the extent of calcification. CMR may be useful for the detection and quantification of myocardial fibrosis, providing additional prognostic information regardless of the presence of coronary artery disease (CAD). Before transcatheter aortic valve implantation CT is the preferred imaging tool to assess the anatomy and dimensions of the aortic root, size and shape of the aortic valve annulus, its distance to the coronary ostia, the distribution of calcifications and the number of aortic valve cusps. CMR—as an alternative technique—is, in this context, inferior to CT with regards to assessment of inner vessel dimensions and calcifications.

In tricuspid regurgitation, when available, CMR is the preferred method for evaluating RV size and function and represents the gold standard for assessing RV volumes and function.

2017 Appropriateness criteria for the use of cardiovascular imaging in heart valve disease in adults: a European Association of Cardiovascular Imaging report of literaturereview and current practice[6]

CT and CMR are not indicated for routine detection of valve disease but incidental aortic valve calcification on CT chest is an under-recognized indication for echocardiography.

In the assessment of valve disease CMR is: (i) indicated for valve morphology if echo suboptimal; (ii) better than echocardiography for the pulmonary valve and subpulmonary and branch pulmonary artery stenoses; (iii) indicated for transvalvar forward flow if echo recordings poor; (iv) indicated for grading mitral or aortic regurgitation if uncertain on echocardiography or additional quantification required; (v) better than echocardiography for grading pulmonary regurgitation. CT/CMR are not indicated if echocardiographic data are consistent with the clinical formulation. In the assessment of LV and RV response CMR is indicated if accurate RV volumes are required. In the assessment of aorta, CT or CMR are indicated: (i) at baseline unless echocardiographic images certain; (ii) if echocardiographic image quality good repeat as threshold for surgery approaches (CT better as this allows coronary anatomy and an assessment of aortic calcification); (iii) if echocardiographic imaging suboptimal (CMR).

In the risk assessment, CMR has no clear clinical role currently but this is likely to develop based on regurgitant volume (in aortic and mitral regurgitation), LV volumes, evidence of fibrosis. In the surveillance, CT/CMR are indicated for aortic dilatation if echocardiographic imaging suboptimal or region of dilatation beyond echo window.

Pre-operative in cardiac surgery for valve disease, CMR is indicated for aorta if CT not needed for angiography, or for viability if myocardial infarction possible/present. Post-operative, CT and CMR are not indicated.

CONGENITAL HEART DISEASE

2020 ESC Guidelines for the management of adult congenital heart disease[7]

Indications for CMR in adult congenital heart disease patients (ACHD) patients include: (i) quantification of RV volumes, EF (including subpulmonary RV, systemic RV, and single ventricle); (ii) evaluation of RV outflow tract obstruction (RVOTO) and RV to pulmonary artery (PA) conduits; (iii) quantification of pulmonary valve regurgitation (PR); (iv) evaluation of PAs (stenoses, aneurysms) and the aorta [aneurysm, dissection, coarctation (CT may be superior)]; (v) evaluation of systemic and pulmonary veins (anomalous connection, obstruction, coronary venous anatomy pre-procedure, etc.); (vi) collaterals and arteriovenous malformations (CT may be superior); (vii) coronary anomalies and CAD (CT is superior for intramural course, slit-like course, acute angle take-off, myocardial bridging, and plaque assessment); (viii) detection and quantification of myocardial ischaemia by CMR stress perfusion; (ix) evaluation of intra- and extracardiac masses; (x) quantification of myocardial mass (LV and RV); (xi) detection and quantification of myocardial fibrosis/scar (LGE, T1 mapping) and tissue characterization (fibrosis, fat, iron, etc.); (xii) quantification of systemic and pulmonary blood flow to calculate of pulmonary to systemic flow ratio (Qp:Qs); (xiii) quantification of perfusion distribution to the right/left lung; (xiv) measurement of pulmonary blood flow in patients with

multiple sources of blood supply (i.e. with major aorto-pulmonary collateral arteries).

ICD implantation should be considered in selected tetralogy of Fallot (TOF) patients with multiple risk factors for SCD, including LV dysfunction, non-sustained, symptomatic VT, QRS duration ≥180 ms, extensive RV scarring on CMR, or inducible VT at programmed electrical stimulation (class IIa recommendation, level of evidence C). Electrophysiologic evaluation, including programmed electrical stimulation, should be considered for risk stratification for SCD in TOF patients with additional risk factors (LV/RV dysfunction; non-sustained, symptomatic VT; QRS duration ≥180 ms, extensive RV scarring on CMR) (class IIa recommendation, level of evidence C). Pulmonary valve replacement is recommended in symptomatic TOF patients with severe PR (regurgitant fraction by CMR >30-40%) and/or at least moderate RVOTO (peak velocity >3 m/s) (class I recommendation, level of evidence C).

In cases with RV-PA conduits, symptomatic patients with RV systolic pressure >60 mmHg (may be lower in case of reduced flow) and/or severe PR (regurgitant fraction by CMR >30-40%) should undergo intervention with preference for catheter intervention if anatomically feasible (class I recommendation, level of evidence C).

Non-pharmacological functional imaging (e.g. nuclear study, echocardiography, or CMR with physical stress) is recommended in patients with coronary anomalies to confirm/exclude myocardial ischaemia (class I recommendation, level of evidence C).

2018 Imaging the adult with congenital heart disease: a multimodality imaging approach—position paper from the EACVI[8]

The choice of imaging modalities should be made by determining the best combination of tests with the least risk to the patient given a specific clinical question.

Echocardiography remains the first imaging modality to use and in many instances will provide all information required for patient management. If echocardiography is of poor quality and cannot therefore provide sufficient information, CMR will in general be the next choice for further evaluation. CMR is also being increasingly used when echocardiography is of good quality but provides borderline or ambiguous measurements of parameters that are essential for the decision-making (catheter intervention, cardiac surgery) such as RV volumes and EF or quantification of valvular regurgitation and shunt lesions.

Key points regarding CMR imaging in ACHD include: (i) a baseline CMR is recommended for many patients at time of transition from paediatric to ACHD programmes; (ii) CMR is the gold standard for ventricular volumes, EF, flow quantification, and the assessment of extracardiac anatomy; (iii) CMR frequency should be determined by the underlying defect and clinical status of the individual patient; (iv) intervals between scans depend on the risk profile, findings at the first CMR study, and the expected rate of change. Intervals of 3 years or more are appropriate in most cases, but earlier restudy may be prompted by the onset or progression of symptoms, or the presence of a lesion liable to rapid progression; (v) additionally, CMR is recommended in the presence of clinical deterioration, non-diagnostic echo findings, and prior to surgical or transcather intervention; (vi) CMR studies should be supervised and reported by appropriately trained ACHD specialists.

AORTIC DISEASE

2018 ESC Guidelines for themanagement of cardiovascular diseases during pregnancy[9]

All women with known cardiac or aortic disease who wish to embark on pregnancy require timely pre-pregnancy counselling. In case of aortic pathology, complete aortic imaging by CT scanning or MRI is necessary for appropriate pre-conception counselling. Imaging of the entire aorta (CT/MRI) is recommended before pregnancy in patients with a genetically proven aortic syndrome or known aortic disease (class I recommendation, level of evidence C).

In pregnancy, MRI is advised if other non-invasive diagnostic measures are not sufficient for definitive diagnosis, and is preferred to ionizing radiation based imaging modalities when possible. Evidence regarding gadolinium-based contrast in pregnancy is controversial and its use should be avoided if possible, especially in the first trimester. For imaging of pregnant women with dilatation of the distal ascending aorta, aortic arch, or descending aorta, MRI (without gadolinium) is recommended (class I recommendation, level of evidence C). Excretion of gadolinium-based agents into breast milk is limited. Data suggest that it is safe to continue breastfeeding after the administration of such agents.

As a general consideration in pregnancy, MRI (without gadolinium) should be considered if echocardiography is insufficient for a definite diagnosis (class IIa recommendation, level of evidence C).

2014 ESC Guidelines on the diagnosis and treatment of aortic diseases[10]

With its ability to delineate the intrinsic contrast between blood flow and vessel wall, MRI is well suited for diagnosing aortic diseases. The salient features necessary for clinical decision-making, such as maximal aortic diameter, shape and extent of the aorta, involvement of aortic branches in aneurysmal dilation or dissection, relationship to adjacent structures, and presence of mural thrombus, are reliably depicted by MRI. In the acute setting, MRI is limited because it is less accessible, it is more difficult to monitor unstable patients during imaging, and it has longer acquisition times than CT. MRI does not require ionizing radiation or iodinated contrast and is therefore highly suitable for serial follow-up studies in (younger) patients with known aortic disease.

Regarding, the role of MRI in the diagnostic work-up of acute aortic syndromes, in case of uncomplicated Type B aortic dissection (AD) treated medically, repeated imaging (CT or MRI) during the first days is recommended (class I recommendation, level of evidence C). Further, in stable patients with a suspicion of abdominal aortic aneurysm (AAS), CT/MRI are recommended (or should be considered) according to local availability and expertise (class I recommendation, level of evidence C). In case of initially negative imaging with persistence of suspicion of AAS, repetitive imaging (CT or MRI) is recommended (class I recommendation, level of evidence C).

In uncomplicatedc Type B intramural haematoma, repetitive imaging (MRI or CT) is indicated (class I recommendation, level of evidence C). In uncomplicated Type B penetrating aortic ulcer, repetitive imaging (MRI or CT) is indicated (class I recommendation, level of evidence C).

Regarding management of chronic aortic diseases, contrast CT or MRI is recommended, to confirm the diagnosis of chronic AD (class I recommendation, level of evidence C).

In patients with thoracic aortic aneurysm - when rates of progression have an impact on the therapeutic decision, they should be assessed using alternative techniques (e.g. TTE and CT or MRI).

Cardiac MRI or CT is indicated in patients with bicuspid aortic valve when the morphology of the aortic root and the ascending aorta cannot be accurately assessed by TTE (class I recommendation, level of evidence C). In the case of aortic diameter > 50 mm or an increase > 3 mm/year measured by echocardiography, confirmation of the measurement is indicated, using another imaging modality (CT or MRI) (class I recommendation, level of evidence C). From a diameter of 45 mm, annual follow-up of the ascending aorta is advised. Annual imaging with MRI (or CT if MRI is not possible) is indicated if TTE cannot reliably visualize the ascending aorta.

For follow-up after (thoracic) endovascular aortic repair in young patients, MRI should be preferred to CT for MRI compatible stent grafts, to reduce radiation exposure (class IIa recommendation, level of evidence C).

Regarding interventions in the case of coarctation of the aorta, independent of the pressure gradient, hypertensive patients with >50% aortic narrowing relative to the aortic diameter at the diaphragm level (on MRI, CT, or invasive angiography) should be considered for intervention (class IIa recommendation, level of evidence C). Independent of the pressure gradient and presence of hypertension, patients with >50% aortic narrowing relative to the aortic diameter at the diaphragm level (on MRI, CT, or invasive angiography) may be considered for intervention (class IIb recommendation, level of evidence C).

PERICARDIAL DISEASE

2015 ESC Guidelines for the diagnosis and management of pericardial diseases[11]

In the diagnosis of acute pericarditis, additional to criteria for an inflamatory pericardial syndrome (pericarditic chest pain, pericardial rubs, new widespread ST-elevation or PR depression on ECG, pericardial effusion), supporting findings include, besides elevation of markers of inflammation, also evidence of pericardial inflammation by CT/CMR. CT and/or CMR may provide confirmatory findings to support the diagnosis of recurrent pericarditis in atypical or doubtful cases showing pericardial inflammation through evidence of edema and contrast enhancement of the pericardium.

CT and/or CMR are recommended as second-level testing for diagnostic workup in pericarditis (class I recommendation, level of evidence C).

The diagnosis of predominant pericarditis with myocardial involvement, or „myopericarditis", can be clinically established if patients with definite criteria for acute pericarditis show elevated biomarkers of myocardial injury without newly developed focal or diffuse impairment of LV function in echocardiography or CMR. In cases of pericarditis with suspected associated myocarditis, CMR is recommended for the

confirmation of myocardial involvement and to rule out ischemic myocardial necrosis in the absence of significant coronary disease; this has clinical and therapeutic implications.

CT or CMR should be considered in suspected cases of loculated pericardial effusion, pericardial thickening and masses, as well as associated chest abnormalities (class IIa recommendation, level of evidence C). In a patient with clinical suspicion of cardiac tamponade, several diagnostic tools are required. Echocardiography is the single most useful diagnostic tool to identify pericardial effusion and estimate its size, location and degree of haemodynamic impact. CT and CMR are often less readily available and are generally unnecessary unless Doppler echocardiography is not feasible.

A diagnosis of constrictive pericarditis is based on the association of signs and symptoms of right heart failure and impaired diastolic filling due to pericardial constriction by one or more imaging methods, including echocardiography, CT, CMR, and cardiac catheterization. The utility of CMR in constrictive pericardial disease is well established, providing the opportunity not only to evaluate pericardial thickness, cardiac morphology and function, but also for imaging intrathoracic cavity structures, allowing the differentiation of constrictive pericarditis from RCM. Assessment of ventricular coupling with real-time cine CMR during free breathing allows an accurate evaluation of ventricular interdependence and septal bounce. Thus, CT and/or CMR are indicated as second-level imaging techniques to assess calcifications (CT), pericardial thickness, degree and extension of pericardial involvement (class I recommendation, level of evidence C). Compared with CT, CMR has the advantage of providing information with regard to the haemodynamic consequences of the non-compliant pericardium on cardiac filling, and has the potential of showing fibrotic fusion of pericardial layers. Imaging techniques for the detection of pericardial inflammation (e.g. CMR) may identify forms of initial reversible constrictive pericarditis, allowing a trial of medical antiinflammatory therapy (2-3 months) that may reduce the need for surgery. Empiric anti-inflammatory therapy may be considered in cases with transient or new diagnosis of constriction with concomitant evidence of pericardial inflammation (i.e.CRP elevation or pericardial enhancement on CT/CMR) (class IIb recommendation, level of evidence C).

In patients with congenital pericardial pathology and pericardial malignancy, CMR shares the advantages of CT, but allows better tissue characterization and the possibility of evaluating the functional consequences. For pericardial cysts, the diagnostic workup includes echocardiography, CT and eventually CMR to define the size, density and neighbouring structures.

2015 European Association of Cardiovascular Imaging (EACVI) position paper: multimodality imaging in pericardial disease[12] (only recommendations)

In acute pericarditis with small or no effusion (non-complicated course), CMR is recommended to confirm clinical diagnosis if clinical context of myocarditis. CT/CMR is not recommended to confirm clinical diagnosis if echocardiography is inconclusive.

In acute pericarditis with complicated course and/or moderate-to-severe effusion and no tamponade, CT/CMR is reasonable: (i) to confirm clinical diagnosis in case of high suspicion of aortic dissection; (ii) to confirm the clinical diagnosis in case of trauma or associated disorders; (iii) to confirm clinical diagnosis if echocardiography inconclusive. CMR is recommended to confirm clinical diagnosis in case of myocarditis and reasonable for follow-up of pericardiocentesis.

Imaging pericardium by CT/CMR is not recommended: (i) in renal failure to confirm clinical diagnosis if echocardiography inconclusive (except non-contrast CT or CMR); (ii) in pregnancy to confirm clinical diagnosis if echocardiography inconclusive. Imaging pericardium by CT/CMR is reasonable post-infarction, to confirm clinical diagnosis if echocardiography inconclusive (e.g. haemopericardium).

For cardiac tamponade and pericardiocentesis, CT/CMR is reasonable (i) to confirm clinical diagnosis in case of high suspicion of aortic dissection and (ii) to confirm the clinical diagnosis in case of trauma and it is not recommended to confirm clinical diagnosis if echocardiography inconclusive. CMR is reasonable for follow-up of pericardiocentesis.

In chronic constrictive pericarditis, CT/CMR is reasonable to confirm clinical diagnosis if echocardiography inconclusive. CMR is recommended for planning pericardiotomy (degree of myocardial fibrosis and atrophy, lung damage,. . .) and is reasonable for follow-up. In effusive - constrictive pericarditis, CT/CMR is reasonable to confirm clinical diagnosis if echocardiography inconclusive. In addition. CMR is reasonable (i) to evaluate inflammation (contrast) and (ii) for follow-up.

In the case of masses and tumours of the pericardium, CT/CMR is recommended to confirm clinical

diagnosis and for further evaluation of the mass and lymphadenopathy detection. For pericardial cysts and diverticula, CT/CMR is recommended to confirm clinical diagnosis. In the congenital absence of the pericardium, CT/CMR is reasonable to confirm clinical diagnosis and associated malformation detection.

CONCLUSIONS

Cardiovascular magnetic resonance is a versatile technique, with proven clinical applications encompassing the whole spectrum of cardiovascular diseases, ranging from coronary syndromes, non-ischemic cardiomyopathies and arrhythmias, to valvular, congenital and aortic diseases as well diseases of the pericardium and cardiac masses. CMR is largely represented in the wide majority of the guidelines and position statements from the European Society of Cardiology and ist working groups or associations, with a growing number of evidence-based specific indications to perform CMR.

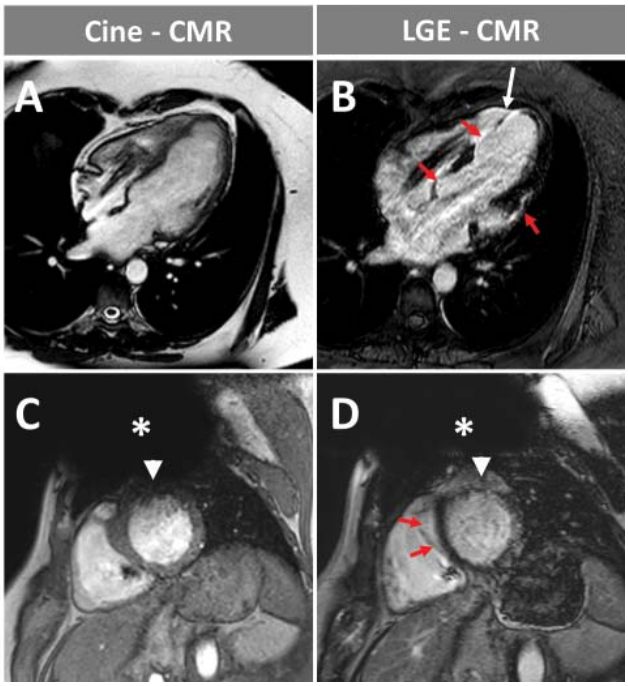

Figure 1. Cine (A, C) and LGE (B, D) images in two device patients with subsequent first diagnosis of cardiac sarcoidosis based on the CMR findings. In the first case (A, B), with pace-maker implantation for third degree atrioventricular block (lead artifact in RA, RV), extensive subepicardial to transmural LGE can be depicted in the septum and lateral wall (red arrows) as well as in the RV apex (white arrow), raising the suspicion of cardiac sarcoidosis. In the second case (C, D), with secondary prophylactic ICD (RV lead artifact) implantation after resuscitated cardiac arrest, subepicardial LGE in the hypertrophied basal anteroseptum can be seen (red arrows), also raising the suspicion of cardiac sarcoidosis. Note the signal loss (*) and artifact in the (not assessable) basal anterior wall (arrow head) caused by the larger generator of the ICD, not present in the case of the pacemaker.

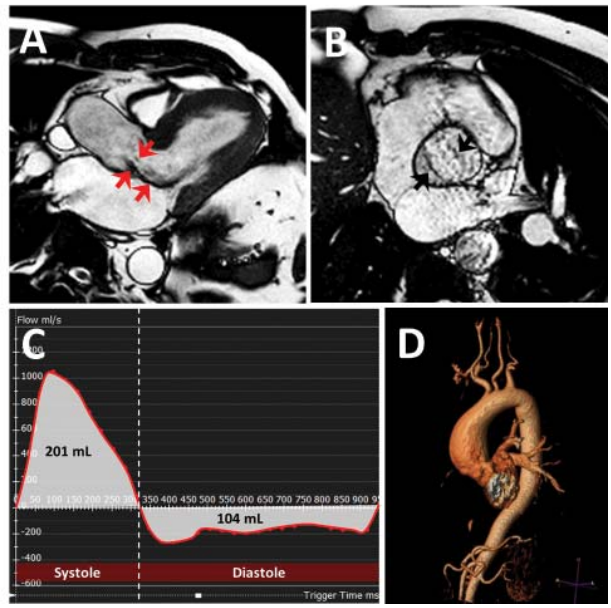

Figure 2. CMR images in a patient with bicuspid aortic valve (fusion of the right and left coronary cusps, B) and severe, eccentric, aortic valve regurgitation (red arrows, A), as shown in the cine images (A, B). The analysis of the flow CMR measurement in the proximal ascending aorta provided a regurgitation fraction of 52%, as calculated by the ratio between regurgitant and systolic (forward) volumes (C). CMR contrast angiography, here as 3D-volume rendering (D), revealed an associated aneurysm of the ascending aorta.

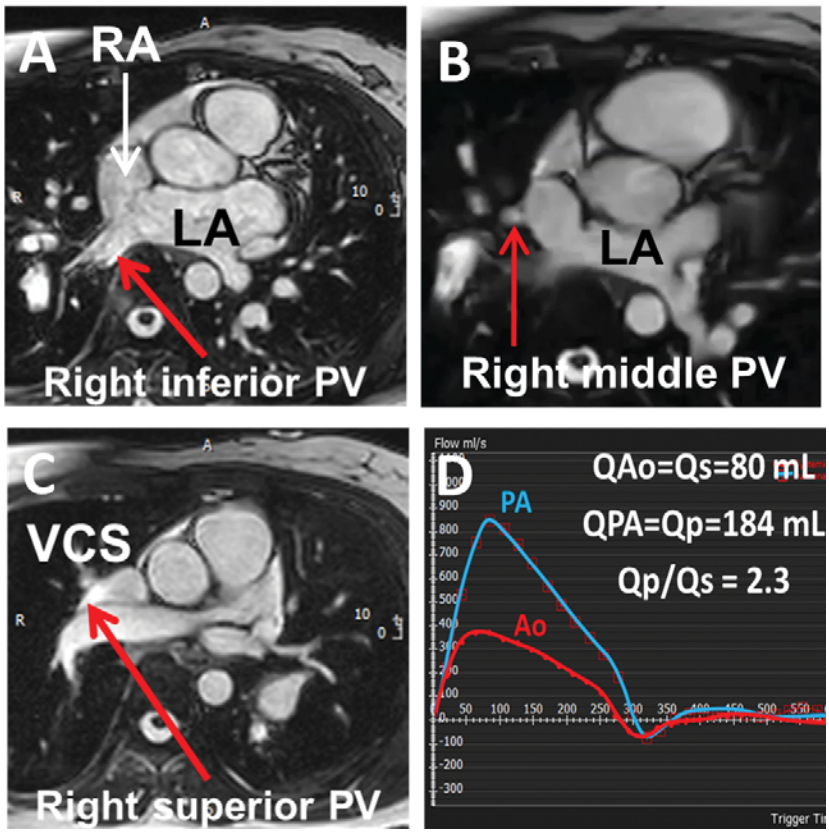

Figure 3. CMR images in a patient with atrial septal defect, superior sinus venosus type. In the cine images (A, B, C), a communication in the upper part of the atrial septum can be seen between the confluence of superior vena cava (VCS) to right atrium (RA) and left atrium (LA). In addition, partial anomalous venous return of the superior right pulmonary vein to VCS (C) and middle right pulmonary vein to the confluence of superior vena cava (VCS) to right atrium (RA) (B) is associated. Flow quantification in the proximal pulmonary artery and ascending aorta revealed a relevant left to right shunt, with a Qp/Qs of 2.3 (D).

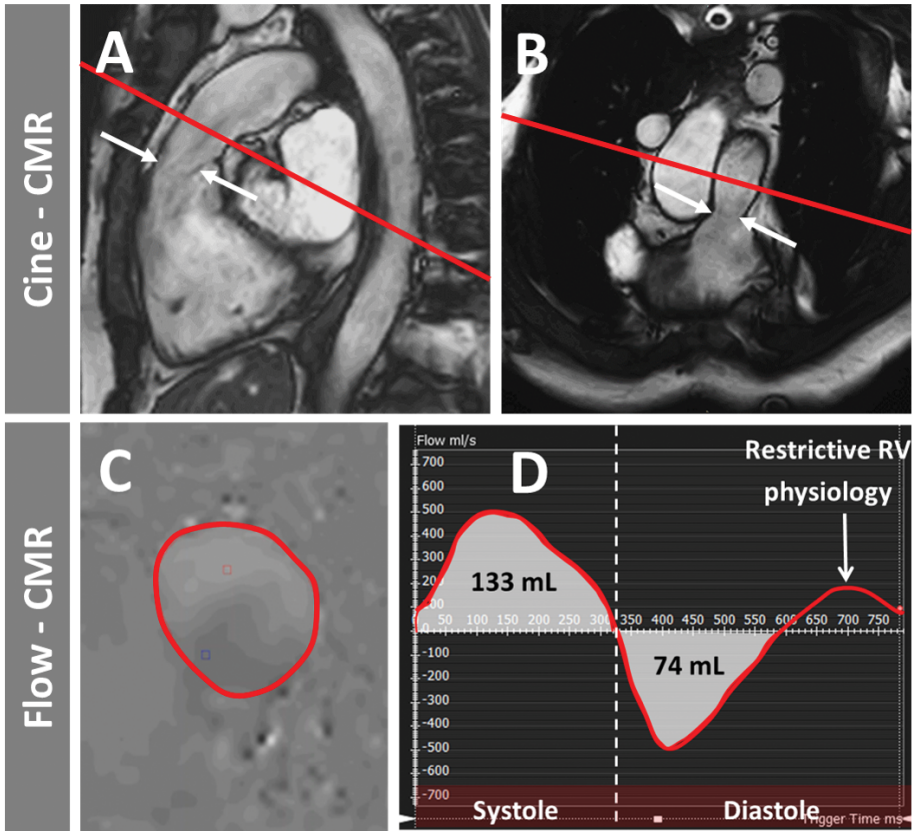

Figure 4. CMR images in a patient with severe pulmonary valve regurgitation after Fallot tetralogy repair. In the cine images (A, B) a wide, almost free, regurgitant jet can be observed (white arrows). A "through plane" flow CMR measurement in the proximal pulmonary artery (C) was planned on the cine images (red lines, A, B) and its analysis revealed a regurgitation fraction of 56% as well as a positive end-diastolic flow suggestive of a "RV restrictive physiology", i.e. increased RV end-diastolic pressure (D).

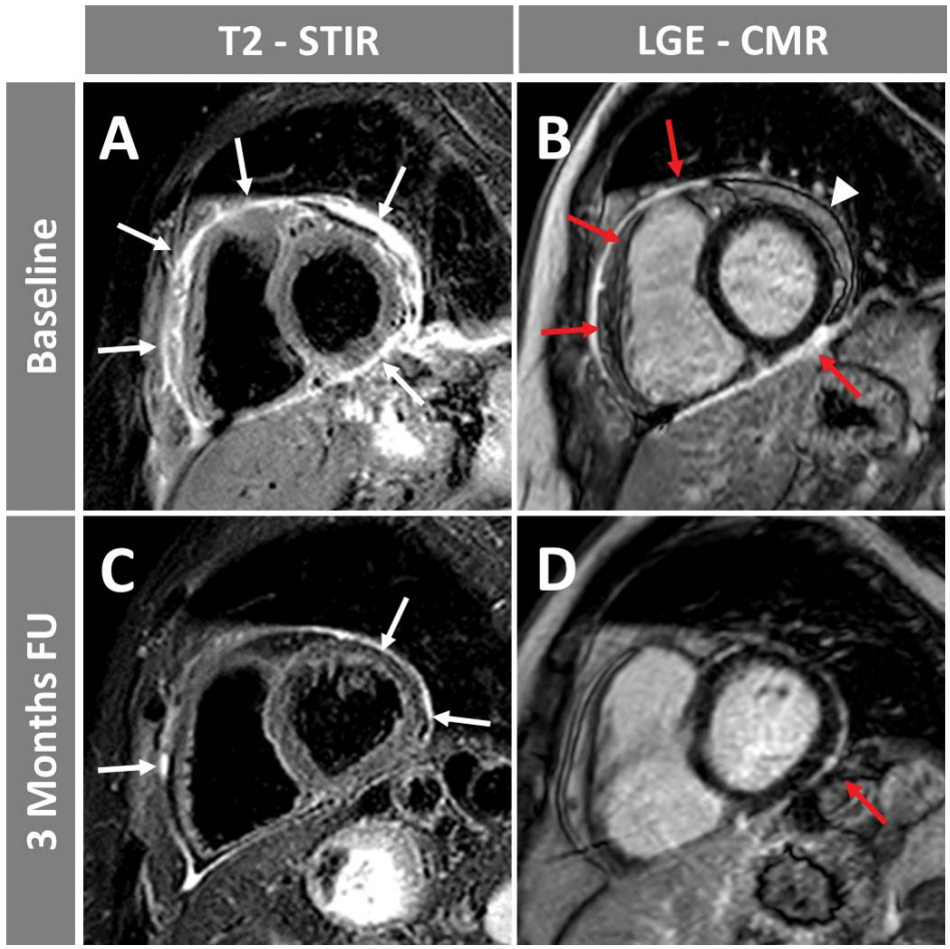

Figure 5. Edema sensitive T2-STIR (A, C) and LGE images (B, D) in a patient with acute pericarditis at baseline (A, B) and follow-up (FU; C, D), after a 3-month course of cortisone and colchicine. At baseline, marked, circular pericardial edema (T2-hyperintensity, A, white arrows) and LGE (B, red arrows) together with a small pericardial effusion (B, arrow heads) are depicted. At FU, an obvious regression of the above changes is noticed, with only minimal residual pericardial edema (C, white arrows) and LGE (D, red arrows) and no effusion.

Compliance with ethics requirements:

The authors declare no conflict of interest regarding this article. The authors declare that all the procedures and experiments of this study respect the ethical standards in the Helsinki Declaration of 1975, as revised in 2008(5), as well as the national law. Informed consent was obtained from all the patients included in the study.

Abbreviations

AAS	abdominal aortic aneurysm
ACHD	adults with congenital heart disease
ARVC	arrhythmogenic right ventricular cardiomyopathy
CMR	cardiovascular magnetic resonance imaging
CT	computed tomography
CAD	coronary artery disease
DCM	dilated cardiomyopathy
ECG	electrocardiogram
HF	heart failure
ICD	implantable cardioverter-defibrillator
LGE	late gadolinium enhancement
LV	left ventricle
MI	myocardial infarction
MRI	magnetic resonance imaging
PM	pace-maker
PA	pulmonary artery
PR	pulmonary valve regurgitation
RV	right ventricle
RVOTO	right ventricular outflow obstruction
SCD	sudden cardiac death
TOF	tetralogy of Fallot
TTE	transthoracic echocardiography
VF	ventricular fibrillation
VT	ventricular tachycardia

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