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The role of cardiac magnetic resonance: European society of cardiology guidelines review

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Introduction. Cardiac magnetic resonance (CMR) imaging is widely used in clinical practice worldwide. The ability to evaluate comprehensively the global and regional systolic ventricular function, characterize the structure of the myocardium, and identify pathologically altered tissues gives a unique value to this imaging modality. Although echocardiography due to its availability remains the most common investigative technique to identify heart disease, CMR is gaining more evidence, and has been included into recent guidelines for the diagnosis and treatment of different origin heart diseases. **Our review aims** to perform a systematic summary of the CMR representation in the guidelines of the European Society of Cardiology (ESC).

Methods. Starting from the year 2010, twenty-five ESC guidelines have been overviewed (listed on the ESC website: https://www.escardio.org/Guidelines/Clinical-Practice-Guidelines) for the terms ”MRI“, ”CMR“, ”MR“, and ”magnetic“. The order of the guidelines starts from the most recent to the oldest. Not imaging-related guidelines were not included in our review. Furthermore, the class of recommendation and level of evidence were obtained (Table 1 and Table 2), as well as the main CMR-related conclusions.

Results. Fifteen of the 25 guidelines (60%) contained specific CMR using recommendations. Nine ESC guidelines (36%) mention and describe the potential benefits of CMR but do not provide the specific recommendation. One guideline (4%, ”2010 Focused update of ESC Guidelines on device therapy in heart failure“) do not mention CMR at all. The 15 guidelines with specific recommendations regarding the use of CMR contain following classes of recommendation: 31 class I, 13 class IIa, 15 class IIb, and 4 class III. Most of the recommendations have evidence level C (40/63; 63.5%), followed by level B (21/63; 33.3%) and level A (2/63; 3.2%).

Conclusions. CMR has become an important imaging tool with important value for the diagnosis and management of cardiovascular disease. While not all ESC guidelines include clear recommendations for CMR application, the usage of CMR is discussed in the large majority of the guidelines.

Keywords: Cardiac magnetic resonance; Magnetic resonance imaging; ESC Guidelines; Cardiology; Radiology.

Introduction

Cardiovascular diseases (CVD) are the leading cause of death worldwide, taking an estimated 17.9 million lives each year[1]. Early diagnosis and management play the main role in patients with suspected or confirmed CVD or individuals with high-risk [1]. During the past two decades, all imaging techniques rapidly evolved and have been applied in subjects with mainly all CVD [2]. Previously the successful application of non-real time imaging techniques has been limited due to suboptimal image quality determined by heart contractions and respiratory movements (non-gated imaging)[3]. Nevertheless, evolving imaging technology allowed the application of highly reliable motion correction techniques, resulting in images with excellent spatial and temporal resolution [3]. Nowadays, the main imaging tool due to its low cost, high temporal resolution, and wide availability is echocardiography [4], although, CMR is gaining strong evidence. CMR allows detailed evaluation of cardiac anatomy and function.– Moreover, it enables to visualize the pathologically altered tissues – the accumulation of gadolinium in the myocardium provides a unique opportunity to image changes in myocardial structure, such as fibrosis, scar or infiltration [7]. The list of most common indications for CMR contains myocardial and pericardial inflammation (myocarditis and pericarditis), ischemic heart disease, cardiomyopathies, valvular heart disease as well as diagnosis and surveillance of rare diseases such as amyloidosis, sarcoidosis or congenital heart disease [5, 6]. CMR usefulness has been concluded into recent European Society of Cardiology (ESC) guidelines for the diagnosis and treatment of different heart diseases [7].

Methods

Starting from the year 2010, twenty-five ESC guidelines were reviewed (available on the ESC website - https://www.escardio.org/Guidelines/Clinical-Practice-Guidelines) for the terms ”MRI“, ”CMR“, ”MR“, and ”magnetic“. The order of the guidelines starts from the most recent to the oldest. The class of recommendation and level of evidence were obtained (Tables 1 and 2), as well as the main CMR-related conclusions.

Table 1. Class of recommendation

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

Table 2. Level of evidence

Level of evidence A	Data derived from multiple randomized clinical trials or meta-analysis.
Level of evidence B	Data derived from a single randomized clinical trial or large non-randomized studies.
Level of evidence C	Consensus or opinion of the experts and/or small studies, retrospective studies, registries.

Results

2019 ESC Guidelines on diabetes, pre-diabetes, and cardiovascular diseases developed in collaboration with the EASD [8]

Patients with altered glucose metabolism are at higher risk for developing cardiac disease. Early risk stratification by the use of laboratory testing, electrocardiogram (ECG), and imaging may be beneficial for these patients. In addition to conventional risk stratification, CMR has demonstrated that patients with diabetes and without coronary artery disease (CAD) might have diffuse myocardial fibrosis, which may lead to LV systolic and diastolic dysfunction. However, the prognostic value of CMR needs further investigation in prospective studies. Another possible complication of diabetes mellitus is lower extremity artery disease (LEAD). In this case, computed tomography (CT) and/or magnetic resonance angiography (MRA) is recommended before scheduled revascularization. Specific recommendations are given in Table 3.

2019 ESC Guidelines for the diagnosis and management of acute pulmonary embolism developed in collaboration with the European Respiratory Society (ERS) [9]

MRA is considered as a promising imaging technique in diagnosing pulmonary artery embolism, and has been evaluated in several extensive studies. However, it has been concluded that MRA is not yet suitable for clinical decision-making due to its lower sensitivity, high number of inconclusive scans, and low availability in emergency departments. Specific recommendations are provided in Table 3.

2019 ESC Guidelines for the management of patients with supraventricular tachycardia [10]

Tachycardia-induced cardiomyopathy (TCM) is a reversible cause of heart failure (HF) and dilated cardiomyopathy, and should be considered in all patients with new-onset of left ventricular dysfunction. In suspected TCM cases, CMR should be considered to exclude intrinsic myocardial structural abnormalities. However, there are no specific recommendations regarding the application of CMR in these guidelines.

2019 ESC Guidelines for the diagnosis and management of chronic coronary syndromes [11]

In initial decision-making, patients with suspected CAD and inconclusive ECG are advised to be tested using CMR as it can provide an important information on cardiac anatomy and global as well as regional myocardial performance. Functional non-invasive imaging, including stress CMR, allows to detect myocardial ischemia through inducible regional wall motion abnormalities. Compared to the 2013 guidelines, there are few new important recommendations regarding the use of CMR. First, non-invasive functional test is recommended as the initial test for diagnosing CAD in symptomatic patients when CAD cannot be excluded by clinical assessment alone. Second, the use of non-invasive functional imaging is recommended in patients in whom computed tomography coronary angiography (CTCA) demonstrated uncertain functional significance CAD. In addition, there are some changes in diagnostic workup in patients with suspected coronary microvascular angina. Recent guidelines

ascertain that non-invasive assessment of coronary flow reserve (CFR) includes not only transthoracic Doppler of the left anterior descending (LAD) artery but also CMR and positron emission tomography (PET). In assessing the risk of adverse cardiovascular events, it is advised to use one of the functional imaging modalities, including stress imaging. Inducible perfusion defects in 2 of 16 segments (myocardial perfusion CMR study) or more than 3 Dobutamine-induced dysfunctional segments detected using stress CMR is a sign of high risk. Patients with a long-standing diagnosis of chronic coronary syndromes (CCS) should be examined regularly, and in the presence of worsening symptoms, it is recommended to repeat functional testing. In patients with severe valvular disease, the routine use of stress CMR is not recommended due to lower diagnostic value and potential risk. Specific recommendations are given in Table 3.

Table 3. Recommendations for CMR in 2019 ESC Guidelines

	Class	Level
2019 ESC Guidelines on diabetes, pre-diabetes, and cardiovascular diseases		
CTCA or functional imaging (radionuclide myocardial perfusion imaging, stress cardiac magnetic resonance imaging, or exercise or pharmacological stress echocardiography) may be considered in asymptomatic patients with diabetes mellitus (DM) for screening of CAD.	IIb	B
Detection of atherosclerotic plaque of carotid or femoral arteries by CT, or magnetic resonance imaging, may be considered as a risk modifier in patients with DM at moderate or high risk CV.	IIb	B
CT angiography or magnetic resonance angiography is indicated in case of lower extremity artery disease (LEAD) when revascularization is considered.	I	C
2019 ESC Guidelines for the diagnosis and management of acute pulmonary embolism		
MRA is not recommended for ruling out pulmonary embolism.	III	A
2019 ESC Guidelines for the diagnosis and management of chronic coronary syndromes		
Risk stratification, preferably using stress imaging or coronary CTA, or alternatively exercise stress ECG (if significant exercise can be performed and the ECG is amenable to the identification of ischaemic changes), is recommended in patients with suspected or newly diagnosed CAD.	I	B
If coronary CTA is available for event risk stratification, additional stress imaging should be performed before the referral of a patient with few/no symptoms for invasive coronary angiography.	IIa	B
In the initial diagnostic management, CMR may be considered in patients with an inconclusive echocardiographic test.	IIb	C
Non-invasive functional imaging for myocardial ischaemia or coronary CTA is recommended as the initial test for diagnosing CAD in symptomatic patients in whom obstructive CAD cannot be excluded by clinical assessment alone.	I	B
Functional imaging for myocardial ischaemia is recommended if coronary CTA has shown CAD of uncertain functional significance or is not diagnostic.	I	B
In high-risk asymptomatic adults (with diabetes, a strong family history of CAD, or when previous risk-assessment tests suggest a high risk of CAD), functional imaging or coronary CTA may be considered for cardiovascular risk assessment.	IIb	C
In low-risk non-diabetic asymptomatic adults, coronary CTA or functional imaging for ischaemia are not indicated for further diagnostic assessment.	III	C
In people with long-standing diagnosis of chronic coronary syndrome, risk stratification is recommended for patients with new or worsening symptom levels,	I	B

preferably using stress imaging or, alternatively, exercise stress ECG.		
Transthoracic Doppler of the LAD, CMR, and PET may be considered for non-invasive assessment of coronary flow reserve.	IIb	B
In asymptomatic adults (age >40 years) with diabetes, functional imaging or coronary CTA may be considered for advanced cardiovascular risk assessment.	IIb	B
In severe valvular heart disease, stress testing should not be routinely used to detect CAD because of the low diagnostic yield and potential risks	III	C

2018 ESC/ESH Clinical Practice Guidelines for the Management of Arterial Hypertension [12]

In patients with hypertension-mediated organ damage, CMR has demonstrated higher sensitivity to detect treatment-induced left ventricular hypertrophy changes when compared with echocardiography. There is still missing data about the prognostic value of the hypertophic changes and no specific recommendation regarding CMR.

2018 Fourth universal definition of myocardial infarction [13]

CMR gives an ability to assess bi-ventricular function, myocardial perfusion, and scar using late gadolinium enhancement (LGE), which is a marker of prior myocardial infarction (MI). CMR can also be used to detect other myocardial injury features, such as the presence and extent of myocardial edema, myocardial salvage index, microvascular obstruction, intramyocardial hemorrhage or infarct size that have prognostic value. In difficult cases of acute MI, when coronary artery obstruction is not detected, CMR can help to diagnose alternative conditions such as myocarditis, Takotsubo syndrome, embolic infarction, or MI with spontaneous coronary artery recanalization. Despite clear benefits of CMR in such clinical situation, document does not provide clear statement for the CMR application..

2018 ESC Guidelines for the diagnosis and management of syncope [14]

CMR imaging has no specific recommendation in the diagnosis or management of syncope. It has only additional advice that CMR or CT should be considered in selected patients presenting with syncope and suspected structural heart disease when echocardiography is non-diagnostic.

2018 ESC/EACTS Guidelines on Myocardial Revascularization [15]

For the assessment of myocardial viability and ischemia, CMR may be performed in selected patients with HF and CAD that are more likely to benefit from myocardial revascularization. Specific recommendations are given in Table 4.

2018 ESC Guidelines for the management of cardiovascular diseases during pregnancy [16]

The guidelines conclude that CMR should be performed only in cases when other non-invasive diagnostic imaging is not sufficient to substantiate the diagnosis. In addition, the usage of gadolinium-based contrast agent should be avoided if possible, especially in the first trimester of pregnancy. Specific recommendations are given in Table 4.

2017 ESC/EACTS Guidelines for the management of valvular heart disease [17]

These guidelines recognize CMR as a possible diagnostic tool for evaluating the degree of valvular, particularly regurgitant lesions, and assessing ventricular volumes, systolic function, abnormalities of the ascending aorta, and myocardial fibrosis in patients with an inadequate echocardiographic quality or inconclusive results. In aortic regurgitation, CMR can be used to quantify the regurgitant volume and regurgitant fraction and

changes during follow-up, but clinical decision-making for surgical intervention is recommended to be based on CT. For dilated ascending aorta (>40 mm), it is recommended to perform CT or MR angiography. However, there are no specific recommendations regarding CMR usage in this document.

2017 ESC Guidelines on the Diagnosis and Treatment of Peripheral Arterial Diseases [18]

MRA may be a helpful diagnostic tool for peripheral artery imaging, especially in patients with mild to moderate chronic kidney disease. However, due to lower resolution and susceptibility to artifacts, the use of MRA is still limited. There are specific recommendations regarding the use of MRA in this guideline. In carotid artery disease, patients with asymptomatic stenoses can be identified using MRA or duplex ultrasound (DUS). Morphological features associated with increased risk of stroke are intraplaque hemorrhage and lipid-rich necrotic core. In clinical cases with a high-risk of renal artery disease, it is recommended to perform DUS followed by MRA to establish the diagnosis. In addition, MRA provides an excellent characterization of renal arteries, the surrounding vessels, renal mass, and even renal excretion function. MRA (or DUS, or CTA) enables to evaluate the lesions of lower extremity artery disease before revascularization. Specific recommendations are given in Table 4.

2017 ESC Guidelines for the management of acute myocardial infarction in patients presenting with ST-segment elevation [19]

Routine echocardiography after a primary percutaneous coronary intervention is recommended to evaluate ventricular function at rest and exclude early post-infarction mechanical complications. When echocardiography is inconclusive, CMR may be a good alternative. In post-MI patients, LGE-CMR imaging has a high diagnostic accuracy for assessing the transmural myocardial scar. In addition, the presence of dysfunctional viable myocardium by LGE is an independent predictor of mortality. It is considered that performing CMR in 2 weeks after myocardial infarction with non-obstructive coronary arteries can increase the accuracy of its etiology identification. Specific recommendations are given in Table 4.

Table 4. Recommendations for MRI in 2017-2018 ESC Guidelines

	Class	Level
2018 ESC/EACTS Guidelines on Myocardial Revascularization		
Non-invasive stress imaging (CMR, stress echocardiography, SPECT, or PET) may be considered for the assessment of myocardial ischemia and viability in patients with heart failure (HF) and CAD (considered suitable for coronary revascularization) before the decision on revascularization.	IIb	B
2018 ESC Guidelines for the management of cardiovascular diseases during pregnancy.		
MRI (without gadolinium) should be considered if echocardiography is insufficient for a definite diagnosis.	IIa	C
Imaging of the entire aorta (CT/MRI) is recommended before pregnancy in patients with a genetically proven aortic syndrome or known aortic disease.	I	C
For imaging of pregnant women with dilatation of the distal ascending aorta, aortic arch, or descending aorta, MRI (without gadolinium) is recommended.	I	C
2017 ESC Guidelines on the Diagnosis and Treatment of Peripheral Arterial Diseases		
Duplex ultrasound (DUS) (as first-line), CTA and/or MRA are recommended for evaluating the extent and severity of extracranial carotid stenoses.	I	B
When carotid artery stenting (CAS) is being considered, it is recommended that any DUS study be followed either by MRA or CTA to evaluate the aortic arch, as well as the extra- and intracranial circulation.	I	B

When carotid endarterectomy (CEA) is considered, it is recommended that the DUS stenosis estimation be corroborated either by MRA or CTA (or by a repeat DUS study performed in an expert vascular laboratory).	I	C
DUS (as first-line), CTA and MRA are recommended imaging modalities to establish a diagnosis of renal artery disease	I	B
DUS and/or CTA and/or MRA are indicated for anatomical characterization of lower extremity artery disease (LEAD) lesions and guidance for optimal revascularization strategy.	I	C
2017 ESC Guidelines for the management of acute MI in patients presenting with ST-segment elevation		
When echocardiography is suboptimal/inconclusive (during hospital stay), an alternative imaging method (CMR preferably) should be considered.	IIa	C
Either stress echo, CMR, SPECT, or PET may be used to assess myocardial ischaemia and viability, including in multivessel CAD.	IIb	C
When echo is suboptimal or inconclusive (after discharge), alternative imaging methods (CMR preferably) should be considered to assess LV function.	IIa	C

2016 ESC Position Paper on cancer treatments and cardiovascular toxicity [20]

CMR has no specific recommendation, only that it is a helpful tool to evaluate cardiac and extra cardiac structures, left and right ventricle function. In addition, CMR is an excellent test for the comprehensive evaluation of cardiac masses and infiltrative conditions. The use of unique tissue characterization capabilities of CMR (e.g., inflammation and edema) is dependent on the acceptance of T2 and T1 mapping and extracellular volume fraction quantification.

2016 ESC Guidelines for the diagnosis and treatment of acute and chronic heart failure [21]

CMR is the best alternative diagnostic imaging method for echocardiography. It is a gold standard to assess ventricular volumes, myocardial mass, and ejection fraction (EF) of both ventricles. Also, CMR is the method of choice in complex congenital heart diseases and as well as myocardial fibrosis using LGE. Besides, CMR is recommended for myocardial tissue characterization in suspected cases like myocarditis, sarcoidosis, amyloidosis, Chagas disease, Fabry-Anderson disease, left ventricular non-compaction cardiomyopathy, and hemochromatosis. Specific recommendations are given in Table 5.

2015 ESC Guidelines for the management of infective endocarditis [22]

The use of CMR is described in the infective endocarditis complications management. One of the complications is myocarditis. To assess myocardial involvement transthoracic echocardiography (TTE) or cardiac CMR can be used. There are some specific recommendations regarding the use of cranial MRA in assessing neurological complications, but it is not the subject of this review.

2015 ESC Guidelines for the diagnosis and management of pericardial diseases [23]

CMR allows the visualization and characterization of the pericardium and other heart tissues in patients with pericardial disease as well as to identify the consequences of pericardial abnormalities on cardiac function and filling parameters. Because of these advantages, CMR is considered the preferred imaging modality to assess pericardial diseases. In the case of myopericarditis, CMR is the modality of choice in confirming the involvement of myocardium. In addition, CMR provides the opportunity to detect local pericardial effusion, observe its thickening or additional masses. Although echocardiography is still the primary diagnostic tool, CMR and CT can be helpful in some situations diagnosing pericardial effusion or

constrictive pericarditis. Specific recommendations are given in Table 5.

2015 ESC Guidelines for the management of patients with ventricular arrhythmias and the prevention of sudden cardiac death [24]

Recent technological advances in CMR enables precise quantification of cardiac chamber volumes,myocardial mass and ventricular function. It is of high diagnostic value in patients with arrhythmogenic right ventricular cardiomyopathy, and in some other situations when echocardiography is not conclusive or functional testing is required. CMR has been recognized as a prognostic tool in athletes with abnormal ECG and in patients with inflammatory heart disease. Specific recommendations are given in Table 5.

2015 ESC/ERS Guidelines for the diagnosis and treatment of pulmonary hypertension [25]

In this guideline, CMR is recognized as one of the diagnostic tools in evaluating pulmonary hypertension and its consequences. Due to its capability to assess right ventricular size, function, and blood flow, CMR provides useful prognostic information in patients with pulmonary arterial hypertension (PAH). However, there are no specific recommendations.

2015 ESC Guidelines for the management of acute coronary syndromes in patients presenting without persistent ST-segment elevation [26]

CMR can be helpful in detecting changes in myocardial perfusion and regional wall motion abnormalities. It has been reported that a normal stress CMR has a high negative predictive value in patients with acute chest pain[26]. In addition, CMR allows differentiation between old scar tissue and recent myocardial infarction. CMR is recommended for the differential diagnosis between MI and myocarditis or Takotsubo cardiomyopathy. These guidelines conclude only non-specific recommendations for stress imaging. Recommendations are given in Table 5.

Table 5. Recommendations for CMR in 2015-2016 ESC guidelines

2016 ESC Guidelines for the diagnosis and treatment of acute and chronic heart failure		
CMR is recommended for the assessment of myocardial structure and function (including right heart) in subjects with poor acoustic window and patients with complex congenital heart diseases (taking account of contra-indications to CMR).	I	C
CMR with LGE should be considered in patients with dilated cardiomyopathy in order to distinguish between ischaemic and non-ischaemic damage in case of equivocal clinical and other imaging data (taking account of cautions/contra-indications to CMR).	IIa	C
CMR is recommended for the characterization of myocardial tissue in case of suspected myocarditis, amyloidosis, sarcoidosis, Chagas or Fabry disease, non-compaction cardiomyopathy, haemochromatosis (taking account of contra-indications to CMR).	I	C
Non-invasive stress imaging (CMR, stress echocardiography, SPECT, PET) may be considered for the assessment of myocardial ischemia and viability in patients with HF and CAD before the decision on revascularization.	IIb	B
2015 ESC Guidelines for the diagnosis and management of pericardial diseases		
CT and/or CMR are recommended as second-level testing for diagnostic workup in pericarditis.	I	C
Cardiac magnetic resonance is recommended for the confirmation of myocardial involvement in suspected myopericarditis.	I	B
CT or CMR should be considered in suspected cases of loculated pericardial effusion, pericardial thickening and masses, as well as associated chest abnormalities.	IIa	C

In constrictive pericarditis, CT and/or CMR are indicated as second-level imaging techniques to assess calcifications (CT), pericardial thickness, degree and extension of pericardial involvement.	I	C
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).	IIb	C
2015 ESC Guidelines for the management of patients with ventricular arrhythmias and the prevention of sudden cardiac death		
Pharmacological stress testing plus imaging modality is recommended to detect silent ischaemia in patients with VAs who have an intermediate probability of having CAD by age or symptoms and are physically unable to perform a symptom-limited exercise test.	I	B
CMR/CT should be considered in patients with VAs when echocardiography does not provide accurate assessment of LV and RV function or evaluation of structural changes.	IIa	B
CT or CMR should be considered in suspected cases of loculated pericardial effusion, pericardial thickening and masses, as well as associated chest abnormalities.	IIa	C
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 sudden cardiac death in inflammatory heart disease.	IIb	C
Upon identification of ECG abnormalities suggestive of structural heart disease, echocardiography and/or CMR imaging is recommended in athletes.	I	C
2015 ESC Guidelines for the management of acute coronary syndromes in patients presenting without persistent ST-segment elevation		
In patients with no recurrence of chest pain, normal ECG findings and normal levels of cardiac troponin (preferably high-sensitivity), but suspected acute coronary syndrome, a non-invasive stress test (preferably with imaging) for inducible ischaemia is recommended before deciding on an invasive strategy.	I	A

2014 ESC guidelines on diagnosis and management of hypertrophic cardiomyopathy [27]

Numerous parameters provide a semi-quantitative score of left ventricle hypertrophy (LVH). However, for diagnostic purposes, the single most relevant setting, measured by any imaging technique, is the maximum LV wall thickness at any level ≥15 mm, and ≥13 mm in first-degree relatives. Similar to echocardiography, CMR provides information on ventricular function and morphology. It helps to differentiate HCM from hypertensive heart disease and establish the diagnosis of HCM in patients with inadequate echocardiography acoustic windows, poorly visualized LV apex, anterolateral wall, or RV. Moreover, CMR imaging is superior to TTE in the assessment of LV mass, detection of LV apical and anterolateral hypertrophy, aneurysms, thrombi, myocardial crypts, and papillary muscle abnormalities.

CMR is helpful before surgical myectomy or alcohol septal ablation to assess myocardial fibrosis and hypertrophy distribution, and may be considered during follow-up in stable patients or patients with progressive disease. Specific recommendations are given in Table 6.

2014 ESC/ESA Guidelines on non-cardiac surgery: cardiovascular assessment and management [28]

LV function can be assessed before non-cardiac surgery in high-risk surgery (IIb, C). This can be performed by echocardiography, multislice CT, CMR, radionuclide ventriculography, and gated single-photon emission computed tomography (SPECT), all with comparable accuracy. Specific recommendations are given in Table 6.

2014 ESC guidelines on the diagnosis and treatment of aortic diseases [29]

CMR is a valuable imaging method for the full range of aortic disease. CT and CMR are superior imaging tools to transoesophageal echocardiography (TOE) for the assessment of acute aortic dissection. However, CMR is considered the leading technique for diagnosis, with a reported sensitivity and specificity of 98%. It demonstrates the extent of the disease and depicts the distal ascending aorta, aortic arch, and proximal coronary arteries and their involvement in the dissecting process.

Also, CMR can be a valuable imaging tool to differentiate intramural hematoma (IMH) from atherosclerotic thickening or thrombus. After thoracic endovascular aortic repair (TEVAR) surgery, patients have to be followed up in the long term to detect complications using CT or MRI. If stent-graft composites are not paramagnetic, the best alternative to detect pseudoaneurysm, endoleaks, and stent-graft material-related complications are CMR and chest X-ray combination. In cases with the bicuspid aortic valve or inaccurate assessment by TTE, CMR is preferable to visualize the aortic root and ascending aorta. If aortic diameter using echocardiography is >50 mm or an increase >3 mm per year, CT or CMR is the pre-operative gold standard to adequately visualize the entire aorta, identify the affected parts, and to asses post-operative enlargement rates during annual follow-up.

CMR should be an alternative tool in cases for cardiovascular risk assessment in Turner's syndrome as well as for the entire aorta evaluation in suspected extracranial giant cell or Takayasu arteritis. Specific recommendations are given in Table 6.

2013 ESC Guidelines on cardiac pacing and cardiac resynchronization therapy [30]

This guideline focus on the safe use of CMR in patients with implanted cardiac devices. Potential adverse effects of CMR on implanted cardiac devices can be radiofrequency-induced heating of the lead tips, pacing inhibition, asynchronous pacing, loss of programmed data, and others. The prevention of these events is qualified personnel, thorough patient selection, and appropriate CMR scanning parameters. Specific recommendations are given in Table 6.

2010 ESC Guidelines for the management of grown-up congenital heart disease [31]

Cardiac magnetic resonance imaging has become increasingly important in patients with grown-up congenital heart diseases. It enables excellent 3D anatomical reconstruction, which is not restricted by acoustic windows or body size. Moreover, it has rapidly improved spatial and temporal resolution. ESC recommendations have been published separately for each grown-up congenital heart disease [31]. CMR is mainly used for anomaly detection and quantification, volumetric parameters, both ventricles mass and function, evaluation of RV outflow tract and conduits, same as aorta, pulmonary arteries, systemic and pulmonary veins, arteriovenous malformations and collaterals. Moreover, it can quantify pulmonary regurgitation, coronary anomalies, CAD, intra- and extracardiac masses, and characterization of myocardial tissue.

2010 Focused update of ESC Guidelines on device therapy in heart failure [32]

CMR is not mentioned in this guideline.

Table 6. Recommendations for MRI in 2013-2014 ESC guidelines

2014 ESC guidelines on diagnosis and management of hypertrophic cardiomyopathy		
It is recommended that CMR studies be performed and interpreted by teams experienced in cardiac imaging and in the evaluation of heart muscle disease.	I	B
In the absence of contraindications, CMR with LGE is recommended in patients with suspected HCM who have inadequate echocardiographic windows, in order to confirm the diagnosis.	I	C
In the absence of contraindications, CMR with LGE should be considered in patients fulfilling diagnostic criteria for HCM, to assess cardiac anatomy, ventricular function, and the presence and extent of myocardial fibrosis.	IIa	B
CMR with LGE imaging should be considered in patients with suspected apical hypertrophy or aneurysm.	IIa	C
CMR with LGE imaging should be considered in patients with suspected cardiac amyloidosis.	IIa	C
CMR with LGE may be considered before septal alcohol ablation or myectomy, to assess the extent and distribution of hypertrophy and myocardial fibrosis.	IIb	C
CMR may be considered every 5 years in clinically stable patients, or every 2–3 years in patients with progressive disease.	IIb	C
2014 ESC guidelines on the diagnosis and treatment of aortic diseases		
In stable patients with a suspicion of acute aortic syndrome, CMR is recommended (or should be considered) according to local availability and expertise.	I	C
In case of initially negative imaging with persistence of suspicion of acute aortic syndrome, repetitive imaging (CT or CMR) is recommended.	I	C
In case of uncomplicated Type B aortic dissection treated medically, repeated imaging (CT or CMR) during the first days is recommended.	I	C
In uncomplicated Type B intramural hematoma, repetitive imaging (CMR/CT) is indicated.	I	C
In uncomplicated Type B penetrating aortic ulcer, repetitive imaging (CMR/CT) is indicated.	I	C
CMR 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.	I	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 CMR).	I	C
CT or CMR is recommended to confirm the diagnosis of chronic aortic dissection.	I	C
For follow-up after (T)EVAR in young patients, CMR should be preferred to CT for magnetic resonance-compatible stent grafts, to reduce radiation exposure.	IIa	C
2014 ESC/ESA Guidelines on non-cardiac surgery		
Imaging stress testing is recommended before high-risk surgery in patients with more than two clinical risk factors and poor functional capacity (<4 METs).	I	C
Imaging stress testing may be considered before high- or intermediate-risk surgery in patients with one or two clinical risk factors and poor functional capacity (<4 METs).	IIb	C
Imaging stress testing is not recommended before low-risk surgery, regardless of the patient's clinical risk.	III	C
2013 ESC Guidelines on cardiac pacing and cardiac resynchronization therapy		
In patients with conventional cardiac devices, MR at 1.5 T can be performed with a low risk of complications if appropriate precautions are taken (see additional advice).	IIb	B
In patients with MR-conditional PM systems, MR at 1.5 T can be done safely following manufacturer instructions.	IIa	B

Discussion

This systematic review shows that CMR has been recognized as useful imaging modality and the role of CMR in clinical practice has been increasing. It has the ability to evaluate cardiac anatomy, wall motion, chamber volumes, flow velocity and tissue changes with high diagnostic accuracy. Due to these features, CMR is an irreplaceable imaging tool in some clinical situations [33]. The most important indications in ESC Guidelines remains risk evaluation in suspected CAD, management of myocarditis and cardiomyopathies as well as assessment of myocardium viability [6]. There are a number of magnetic resonance techniques and sequences, so it is essential to perceive their value in different clinical applications. For example, dark-blood MR imaging is used to assess vascular abnormalities, cine cardiac MRI to evaluate ventricular volumes and function, LGE-CMR to detect scarring of myocardium, stress CMR to assess ventricular, valvular or ischemic abnormalities [34,35]. Since CMR is considered to be a promising imaging modality, new sequences such as fingerprinting, 4D-flow or diffusor tensor imaging are being introduced and further clinical trials are needed to prove its benefits [36]. Despite being a valuable imaging technique, CMR still has relatively low accessibility, high costs and lack of trained personnel that limits its use [37].

It is important to mention that our study is limited to ESC Guidelines and we discuss only recommendations given in there. There are some evidence that CMR is useful in more clinical situations such as detecting cardiac sarcoidosis, systematic lupus erythematosus, cardiotoxicity and other [36,38]. However, it is not the object of our study.

Conclusions

Cardiac magnetic resonance has become an important part of cardiovascular disease management. The use of CMR is discussed in the vast majority of ESC Guidelines and all recommendations regarding its use are collected in the tables above (*Tables 3-6*). Cardiac magnetic resonance remains the imaging modality of interest and further investigations are being held to determine its possible diagnostic benefits.

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