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Original Research Article

Place of Cardiovascular Magnetic Resonance (CMR) In Cardiovascular Pathology and Its Interest in Aeronautical Expertise

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Abstract

In cardiovascular pathology, cardiovascular magnetic resonance (CMR) has emerged over time as a test with single potential. This non-invasive, non-irradiating, with few contraindications, and economically reasoned examination, finds all its interest in aeronautical expertise of flight crew, in addition to first-line examinations, including electrocardiogram and echocardiography, which do not always allow to decide on the absence of underlying cardiac disease, which would have a consequent impact on the decision of aptitude either in admission or revisional visit. Through this work, we will focus on the technical aspects of CMR namely: different sequences, safety, physical principles, then its main indications according to international learned societies, and finally its interest in aeronautical expertise.
Keywords: Cardiovascular Magnetic Resonance (CMR), Aeronautical expertise, Cardiovascular pathology, Flight crew, Indications.

INTRODUCTION

Cardiovascular magnetic resonance (CMR) is an imaging technique that has been booming for the past ten years. It allows a static and dynamic analysis of the cardiovascular system, providing complementary data to cardiac ultrasonography. Thanks to a good spatial and temporal resolution, a three-dimensional approach, and an excellent contrast between circulating blood and the myocardium, CMR is a reference method for imaging congenital heart disease, heart tumors, large vessels and pericardium [1]. Its major advantage is to be able to associate the study of the myocardial viability, to the analysis of the myocardial perfusion, and to a functional approach of the cardiac muscle by the study of the ventricular functions right and left [2].

Technical Aspects

Physical Principles

The physical principles for obtaining MRI images are complex. The patient is placed in a magnetic field of very high power, allowing a three-dimensional mapping of the signals emitted by the protons of tissues of different densities. The signals emitted by these protons are decomposed along an axis parallel to the magnetic field, corresponding to the relaxation T1, also called longitudinal relaxation, and along an axis perpendicular to the magnetic field, corresponding to the relaxation T2, called transverse relaxation. The T1 and T2 proton relaxations depend on the tissues and make it possible to obtain two contrasting images for the same structure [3].

Safety

CMR is a non-irradiating examination and does not require the use of nephrotoxic iodinated contrast agent. It is an examination that does not cause any harmful phenomenon in the organism. The contrast agent frequently used in these examinations is gadolinium. There is very little restriction on its use. It is contraindicated in pregnant women, in exceptional cases of gadolinium allergy, and in cases of severe renal insufficiency (creatinine clearance <30 ml / min) because of the risk of skin fibrosis in this context (systemic nephrogenic fibrosis) [4].

Different Sequences

Various approaches are possible in CMR, and different sequences will be used depending on the desired information. The most used are:

Spin-Echo Sequence: Morphological Magnetic Resonance Imaging (MRI)

It is a sequence that allows tohave an anatomical static imaging with images of "black blood", giving morphological information on the cardiovascular system (Figure-1).

It is the cardiac MRI selection sequence for the morphological study of large vessels, cardiac tumors, constrictive pericarditis or congenital heart disease [5].

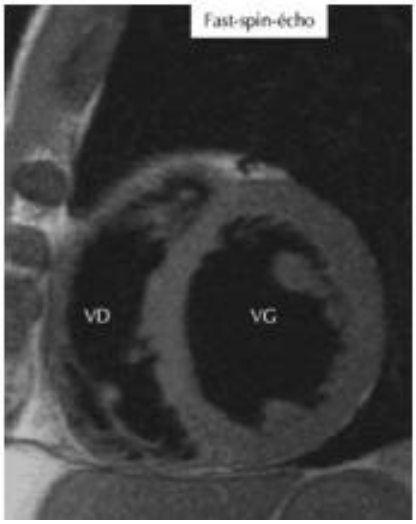

Fig-1: Diastolic static image obtained in fast-spin-echo showing the absence of morphological or structural abnormality in a healthy subject (small-axis cut, perpendicular to the long axis of the heart)

Cine Gradient-Echo Sequence: Cine MRI

Sequence that allows to obtain dynamic imaging with "white blood" images allowing: a very fine analysis of the anatomy and the cardiac function, thanks to its mode in movement, and a detection of possible segmental kinetic disorders. This sequence is, for learned societies, the most accurate and reproducible clinical method for determining left and right ventricular function. This technique also helps diagnose certain complications during various cardiomyopathies, such as mitral leak, intraventricular thrombus (Figure 2), ventricular aneurysm, and pericardial effusion [6].

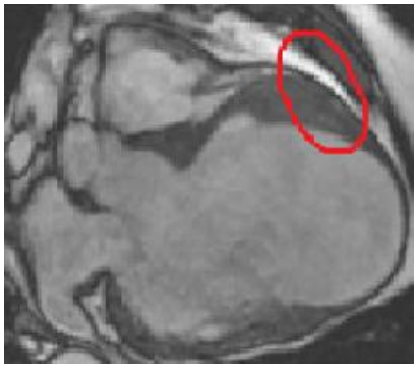

Fig-2: Diastolic image of cine MRI showing a septal wall thrombus in contact with septal transmural necrosis

Cardiac Stress MRI

Stress MRI is a non-irradiating technique that allows the detection of myocardial ischemia, either by imaging of myocardial perfusion during pharmacological stress (adenosine or dipyridamole), or by imaging of ventricular function (cine MRI) during an infusion of increasing doses of dobutamine-atropine in search of abnormalities of segmental kinetics. It has excellent diagnostic accuracy compared to scintigraphic or echocardiographic techniques, and allows the assessment of the location and extent of ischemia, with obvious prognostic implications, especially in the very many situations where the stress test is contentious, not feasible, sub-maximal (Figure-3) or uninterpretable [7].

A direct comparison between stress cine MRI under dobutamine, and MRI perfusion during pharmacological stress under adenosine was performed by Paetsch *et al.*, [8], in the same patients, taking coronarography as a reference method. In this study, dobutamine stress cine-MRI and adenosine perfusion imaging have similar sensitivity (89 and 91%, respectively), but better specificity under dobutamine (80 versus 62%). This lack of specificity in perfusion imaging is probably explained by a higher rate of false positives in relation to magnetic susceptibility artifacts in the septum. This pitfall improves with the learning curve of the myocardial perfusion imaging technique and the better recognition of these artifacts [8].

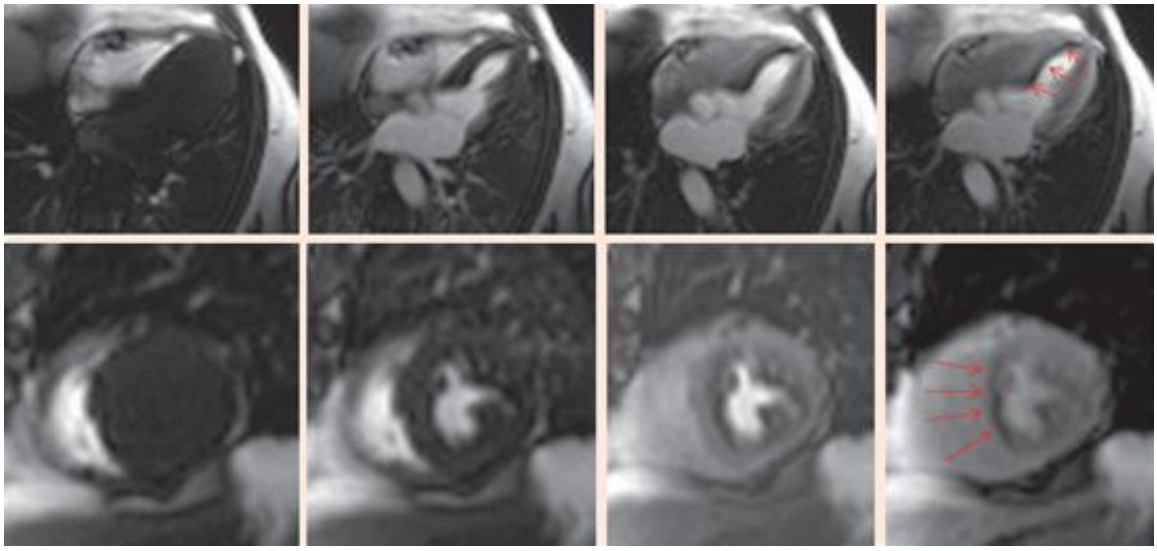

Fig-3: Progressive distribution of gadolinium (from left to right) during dynamic perfusion imaging obtained 3 min after injection of 0.84 mg / kg persantine in a patient with a submaximal exercise test. There is a subendocardial hyposignal zone at the apical septum during stress (arrows)

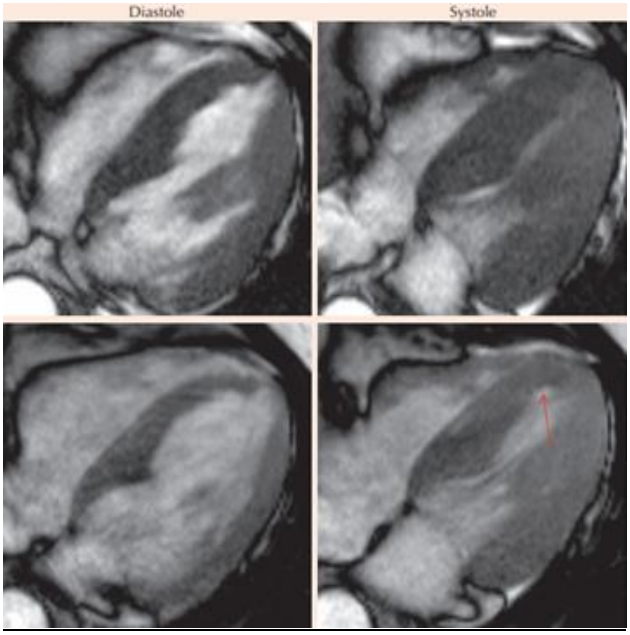

Fig-4: Four Cavity Cine-MRI imaging, recorded before (high) and after stress (low), shows the appearance of septo-apical akinesia, reinforcing the presence of a severe lesion of the left anterior descending coronary

Late Gadolinium Enhancement Sequence: Contrast MRI

One of the major contributions of MRI is the late enhancement imaging performed 10 minutes after gadolinium injection. This type of modality allows high-resolution direct imaging of myocardial infarction or intra-myocardial fibrosis during various cardiomyopathies. MRI contrast has become the clinical reference method for the diagnosis of myocardial viability. The detection of intra-myocardial fibrosis has a high prognostic value in cases of ischemic ca, hypertrophic, and dilated cardiomyopathy [9, 10].

Mapping Flow

Allows the quantification of flow in CMR and uses the same principles as those developed for angio-MRI in contrast phase. Contrast phase flow imaging provides access to quantification of velocities and blood flow [11].

Coronary MRI

The small diameter, the tortuous and complex anatomy of the coronary arteries as well as the incessant cardiorespiratory movements makes the evaluation of the coronaries by MRI very difficult [12]. Another approach to detecting coronary heart disease is to measure the velocity of coronary flow by MRI. Indeed, different methods allow the evaluation of blood flow

velocities in MRI. The application of these methods to the measurement of coronary flow rates at rest and after stress (adenosine), allows a precise and comparable evaluation to the endocoronary Doppler coronary reserve, particularly useful to assess the functional character of a stenosis [13].

Sequence of Myocardial Tagging

Myocardial tagging is a technique that is useful in assessing ventricular function. By modulating the magnetization gradient, the signal from the myocardium can be nulled in a grid pattern prior to the onset of image acquisition. At imaging, this dark appearing grid moves with the tissue that was tagged by the null signal. Areas of myocardium that are not contracting appropriately will demonstrate decreased deformation of the grid during the cardiac cycle. Additionally, tagging can be applied to imaging of pericardial disease to evaluate for areas of thickened pericardium adhered to the myocardium. It allows an even finer analysis of segmental ventricular function, giving access to fine quantitative parameters of myocardial deformation [14].

Indications

According to the consensus conference published by the cardiovascular magnetic resonance working group of the European Society of Cardiology [15], and according to recent findings of the work of the American Cardiology and Cardiac Imaging Societies [16], and on current data from the literature, the usefulness of CMR in specific diseases is summarized by means of the following classification:

- *Class I* = provides clinically relevant information and is usually appropriate; may be used as first line imaging technique; usually supported by substantial literature.
- *Class II* = provides clinically relevant information and is frequently useful; other techniques may provide similar information; supported by limited literature.
- *Class III* = provides clinically relevant information but is infrequently used because information from other imaging techniques is usually adequate.
- *Class IV* = potentially useful, but still investigational.

CMR has an interest in various cardiovascular pathologies, and may be indicated first, or in addition to other conventional cardiac investigations such as echocardiography.

Congenital Heart Disease

One of strengths of CMR is the evaluation of patients with congenital heart disease (CHD), because 3D contiguous data sets are very effective for the complete depiction of the pathological anatomy of both simple and complex CHD.

CMR is usually performed following, and as an adjunct to transthoracic echocardiography in neonates and infants. In contrast, CMR becomes the first line technique when in older children, in adolescents or adults, in more complex anatomy, or at any age after surgery because body habitus and interposition of scar tissue and lungs become an increasing problem for transthoracic echocardiography [17, 18]. Also, prior use of CMR can minimize duration and risks of diagnostic catheterization [19]. For a reliable study, a thorough understanding of the anatomic and functional principles of CHD is nevertheless required, although CMR techniques are generally less operator dependent than echocardiography. This requires experience and training guidelines have been published [20]. The following specific congenital anomalies, are the situations when CMR can be used : anomalies of the viscero-atrial situs [21], the atria and venous anomalies [22], anomalies of the atrioventricular connections [19], *anomalies of the ventricles and valves [23]*, *anomalies of the great arteries and conduits [24]*, *in* Post-operative CHD [25], c*oronary artery anomalies* [26] *especially* in defining congenital or inflammatory changes of the coronary arteries as in Bland-White-Garland syndrome, and Kawasaki disease.

Acquired Vascular Disease

A variety of acquired vascular disease can be evaluated by CMR, in addition to morphologic imaging of blood vessels, velocity mapping can be used to assess and measure the blood flow. The most important CMR's indications in acquired vascular disease are summarized in the following table (Table-1) [27-30].

Table-1: Indications for CMR in acquired diseases of the vessels

Indications	Class
- Diagnosis and follow-up of: thoracic aortic aneurysm including Marfan disease, chronic aortic dissection, aortic intramural haemorrhage, penetrating ulcers of the aorta. - Pulmonary artery anatomy and flow. - Assessment of thoracic, abdominal and pelvic veins, renal arteries, iliac, femoral and lower leg arteries, thoracic great vessel origins, cervical carotid arteries, and pulmonary veins.	**I**
- Diagnosis and planning of stent treatment for abdominal aortic aneurysm. - Diagnosis of acute aortic dissection. - Assessment of mesenteric arteries.	**II**
- Diagnosis of central pulmonary emboli. - Assessment of atherosclerotic plaque in carotid artery/ aorta.	**III**

Coronary Artery Disease

There are several approaches to detecting CAD using CMR. These include the visualization of the effects of induced ischemia (wall motion, perfusion) and direct visualization of coronary arteries (coronary angiography and flow). Indeed, new avenues for assessing coronary artery disease (CAD) and its consequences have been opened by CMR. Before, diagnostic tools such as echocardiography and nuclear cardiology, currently dominated non-invasive diagnosis in patients with CAD, but now, CMR provides valuable information which may not be available from others diagnostic tools mentioned above. The main indications of CMR in coronary artery disease are summarized in the following table (Table-2) [9, 31-35].

Table-2: Main indications for CMR in coronary artery disease

Indications	Class
- Assessment of global ventricular (left and right) function and mass.	I
- Detection of coronary artery disease :	
+Regional left ventricular function at rest and during dobutamine stress	II
+Assessment of myocardial perfusion	II
+ Coronary MRA (CAD)	III
+Coronary MRA of bypass graft patency	II
+MR flow measurements in the coronary arteries	IV
- Acute and chronic myocardial infarction:	
+Detection and assessment	I
+Myocardial viability	I
+Ventricular septal defect	III
+Mitral regurgitation (acute MI)	III
+Ventricular thrombus	II
+Acute coronary syndromes	IV

MRA: Magnetic Resonance Angiography, MI: Mitral Insufficiency

Non Ischemic Cardiomyopathies

CMR is proving increasingly valuable in the identification and management of the cardiomyopathies, which include a variety of diseases where the primary pathology directly involves the myocardium excluding CAD. Among the most frequent and important non ischemic cardipathies, we can describe first of all: Hypertrophic cardiomyopathy, in which CMR finds all its interest, because of its 3D nature, which allows for the precise definition of the site and the extent of hypertrophy, especially at the left ventricular apex which may not be well assessed by echocardiography, which can lead to underdiagnosis of apical HCM [36, 37]. Concerning Left ventricular hypertrophy, which is an important independent risk factor for cardiac events, CMR is the best technique for assessing left ventricular mass and following its progression over time, because of excellent interstudy reproducibility [38, 39]. CMR may be useful to depict the anatomic and functional abnormalities associated with infiltrative/ restrictive cardiomyopathy [40], and dilated cardiomyopathy [41]. However, Arrhythmogenic right ventricular cardiomyopathy remains the lighthouse rhythmic indication of CMR, because it is an ideal technique to depict the structural and functional abnormalities of the right ventricular [42]. About Cardiac sarcoidosis, sudden death may be its initial clinical presentation and early detection of such involvement is thus important, however, clinical information and standard imaging techniques suffer from low diagnostic accuracy [43], hence the value of CMR, which demonstrates increased signal in hearts affected by sarcoidosis, and which therefore, reduces with steroid treatment, mortality [44]. Finally, CMR has a role in the diagnostic of siderotic cardiomyopathy [45] and myocarditis [6].

Pericardial Disease, Cardiac Tumors and Valvular Heart Disease

In the search for pericardial effusion, ultrasound remains the first-line examination, however, CMR may be indicated in case of hemorrhagic or localized (especially anterior) effusions, or when pericardial thickening is suspected [24]. Transthoracic echocardiography is the usual technique which detects intracardiac tumours, however, in many cases the characterization is incomplete, and CMR is particularly helpful in determining the relationship to normal

intracardiac structures and tumour extension to adjacent vascular and mediastinal structures, infiltration into the pericardium, and surgical planning [46]. The primary clinical tool for evaluation of valvular heart disease is transthoracic echocardiography, but CMR has its place in quantification of: severity of regurgitant lesions, and effects of valvular lesions on ventricular volumes, function and myocardial mass [47].

Interest of Cardiac Magnetic Resonance (CMR) In Aeronautical Expertise

CMR finds all its interest in aeronautical medicine because cardiology expertise plays an important role in aeronautical fitness visits. The priority of the aviation medicine expert is to maintain the highest level of air safety, by limiting the risk of sudden or subtle incapacitation in flight. Cardiac pathologies (coronary artery disease, rhythmic heart disease, cardiomyopathy, valvulopathy), which expose to a rich symptomatology: sudden death, syncope but also lipothymia, dyspnea, palpitations, are of particular interest to the expert in aviation medicine.

The expert's diagnostic approach to suspicion of a cardiac pathology involves, first of all, the interrogation in search of a family history of cardiomyopathy or sudden death, followed by a detailed clinical examination and the electrocardiogram. This initial approach is followed by specific cardiac investigations, such as transthoracic echocardiography, which has several limitations: echogenicity of the subject, difficult visualization of the apical segments, not to mention the dependent operator character. Some contentious situations may require a formal diagnosis to determine the capacity, hence the value of CMR [48].

The first interest of CMR in aeronautics, resides in case of suspicion of Arhytmogenic Right Ventricular Dysplasia (Figure-5), and this in front of a bundle of clinical arguments, namely, family history of sudden death or functional signs with the effort, or in front of one of the following electrophysiological arguments in particular: complex ventricular extrasystoles from the right ventricle, persistence of benign ventricular extrasystoles, presence of epsilon wave [49] (Figure-6).

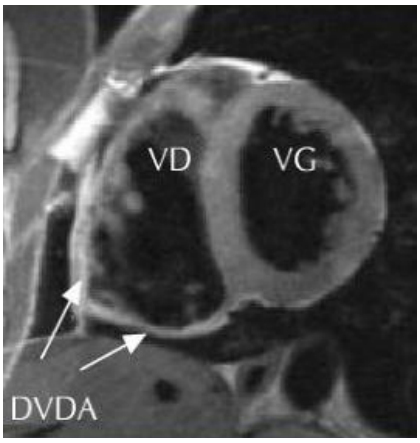

Fig-5: Image of Morphological MRI in a spin-echo sequence showing arhythmogenic right ventricular dysplasia

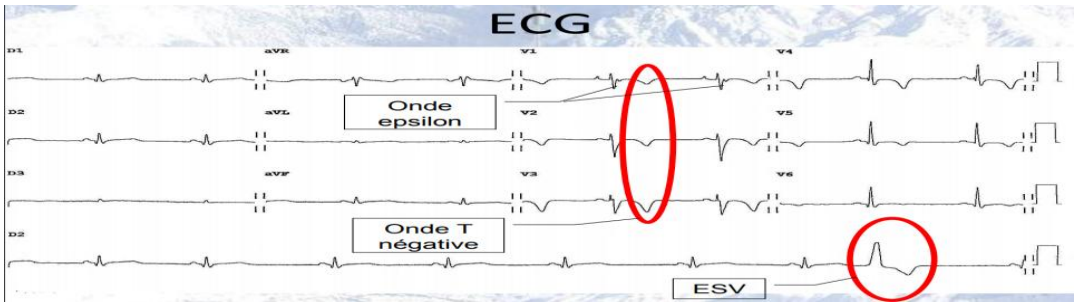

Fig-6: Electrocardiogram showing ventricular extrasystoles, repolarization disorder and epsilon wave

CMR may be used in aircrew, for diagnostic purposes, if there is suspicion of coronary insufficiency, with a contentious, sub maximal or not feasible stress test. It may be used also for the evaluation of a coronary known flight crew, for example remote from a revascularization procedure as part of its professional rehabilitation [35].

If a systemic inflammatory pathology is discovered in a flight crew during his periodic medical visit, CMR plays an important role in the search for cardiac involvement [6].

For flight crew members suffering from sarcoidosis, regular CMR monitoring is essential, because cardiac involvement in sarcoidosis is

symptomatic in only 5% of cases, and it is frequently responsible for sudden death. Early diagnosis in asymptomatic patients is therefore essential, especially that the initiation of immunosuppressive therapy seems to improve the prognosis of these patients. CMR doesnt only allows the diagnosis of cardiac sarcoidosis, but also allows to follow the evolution of the disease under treatment [43].

Finally, during admission visits, the use of CMR is of great help, in the context of the cardiomyopathie screening especially hypertrophic, in case of significant repolarization disorders and limits left ventricular hypertrophy without further explanation controlled over at least two weeks [49].

CONCLUSION

This is the set of information provided by CMR, namely: cardiac function, perfusion, viability, fibrosis, which makes it an examination with a unique potential. For all these reasons, we can anticipate a rapid development and increasing use of CMR in cardiovascular pathologies, which would have a significant impact on the aeronautics aptitude decisions whether in admission visit or periodic. In addition, CMR presents a real added value in doubtful cases, compared to echocardiography, with a favorable cost / profitability ratio.

Competing Interests

The authors declare that they have no competing interests.

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