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Journal of Interdisciplinary Medicine

REVIEW

CARDIOLOGY // IMAGING

New Developments in Magnetic Resonance Imaging of Myocardial Diseases – Technical Aspects and Clinical Applications

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ARTICLE HISTORY

Received: 9 November, 2016
Accepted: 12 December, 2016

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ABSTRACT

Cardiac magnetic resonance imaging is an evolving imaging method that can be used in cardiovascular pathology evaluation. Technological developments have increased the clinical utility of cardiac magnetic resonance in the exploration of various cardiac abnormalities. The most important imaging techniques and their utility will be presented in this review, together with the advantages and limitations of cardiac magnetic resonance and with a brief presentation of common cardiac disorders that can be assessed by cardiac magnetic resonance including ischemic heart disease, cardiomyopathies and myocarditis.

Keywords: cardiac magnetic resonance imaging, ischemic heart disease, cardiomyopathies, myocarditis

BACKGROUND

Cardiac magnetic resonance imaging (CMR) is an examination of increasing significance in cardiovascular disease (CVD) diagnosis because it is a versatile, noninvasive, and non-irradiating method. Technological developments support the adoption of CMR in a wide array of clinical contexts. Obstacles in image acquisition due to heart movements have been overcome by developing higher field strength systems, dedicated cardiac coils with a larger number of channels, and by increasing the parallel imaging factor.[1] Due to these advancements, acquisition time and signal-to-noise ratio were reduced, while spatial resolution was improved, offering a better imaging quality and diagnostic accuracy.[2]

ADVANTAGES OF CMR

CMR has many advantages when compared with other imaging techniques. CMR has a multi-planar imaging capability and does not use ionizing radiation,

thus it can be used to investigate cardiac and vessel diseases not only in the general population but also in pregnant women and children. Another strength of CMR is its capacity to overcome patient-specific limitations including obesity, the presence of soft tissue and scars, which influence image quality in other methods such as echocardiography.[3]

Acquisition using ECG gating and the possibility to adjust breath hold temporal resolution and free breathing sequences suppress motion artifacts even in patients with respiratory diseases and ensure high quality cross-sectional images.[4]

CMR is an imaging technique that offers not only morphological data but also relevant information on regional and global function of the heart.[5] In comparison with cardiac computed tomography angiography (CCTA), there are several conditions in which contrast medium is not necessary for CMR examination.

Finally, because CMR has a high inter-study reproducibility, it is a useful tool in patient follow-up after therapeutic interventions.[6]

LIMITATIONS OF CMR

Long acquisition time and lower spatial resolution represent the major limitations of CMR.[7] However, this technique has several other disadvantages that are valid for any magnetic resonance imaging (MRI) examination. Absolute contraindications for MRI examination include electrically, magnetically or mechanically activated devices and metallic or ferromagnetic implants such as cardiac pacemakers, defibrillators, cochlear implants, insulin pumps, hearing aids, and neurostimulators.[8] Most of the newer stents, aneurysm clips, and vascular filters are compatible with MRI, but their safety should be checked before examination. Sternal wires, annuloplasty rings, and prosthetic heart valves are considered safe, but metallic artifacts may be present.[1] Because CMR requires patient cooperation, other limitations include claustrophobia and unstable patients. Finally, other impediments are represented by the higher cost and the lower accessibility of this imaging method.

TECHNIQUE

CMR is a flexible method that uses examination protocols that include several sequences, tailored in each individual study to assess a specific pathology or cardiac function.

The major challenge in CMR image acquisition is to overcome motion artifacts caused by cardiac cycle and respiration. Artifacts due to cardiac motion are diminished by using electrocardiogram (ECG) gating in order to acquire images during the diastole. Respiratory movements can be suppressed either by breath hold during data acquisition, or by using the navigator technique in patients unable to hold their breath.[9]

Pulse sequences combine magnetic gradients and radio-frequency pulses and are widely used in CMR image acquisition.[10] The sequences can be divided in black blood imaging and bright blood imaging.

Black blood imaging traditionally includes *spin echo sequences* (SE) and their newer substitutes: fast spin echo (FSE) and turbo spin echo (TSE), with improved signal-to-noise ration and shorter acquisition time.[11] Half-Fourier single-shot fast spin echo (SS-FSE) is the fastest sequence and is developed under different trade names: half-Fourier acquired single shot turbo spin echo — HASTE (Siemens) or SS-FSE (GE).[12] Black blood sequences are characterized by a low signal intensity aspect of fast flowing blood and are mainly used to delineate anatomic structures. They offer high resolution images and are used in the morphologic study of the heart, mediastinum, and great vessels.

Bright blood imaging refers mainly to *gradient echo sequences* (GRE) and the recently introduced *steady state free precision* (SSFP) technique. These sequences describe a high signal intensity aspect of fast flowing blood and are used to assess cardiac function.[11]

The GRE is characterized by speed and versatility, but it is susceptible to metallic artifacts. Different trade names assigned for these sequences are: fast imaging using low angle shot — Turbo FLASH (Siemens) and spoiled grass gradient recall acquisition using steady states — FSPGR (GE).[12] Some of its applications include the assessment of valvular disease, ventricular function, measurements of blood flow and velocity, myocardial perfusion, and delayed enhancing images.

SSFP is an important category of sequences, available under different trade names: true fast imaging with steady state precision — True FISP (Siemens) and fast imaging employing steady state acquisition — FIESTA (GE).[12] These are GRE-related techniques that offer bright blood images with an excellent contrast between blood within the heart and myocardium. Their major applications are wall motion examination and volumetric measurements that require a clear delineation between the blood pool and myocardium.

Inversion recovery (IR) sequences are used to null the signal of a certain tissue in order to accentuate surrounding abnormalities. The most important implementations of IR are short T1 inversion recovery — STIR and fluid attenu-

ated inversion recovery — FLAIR. STIR sequences provide null fat signal, they are not affected by inhomogeneities of the magnetic field unlike classic fat saturation and are excellent in the evaluation of bone marrow edema.[10] In FLAIR sequences, the inversion recovery pulse nulls the signal from the cerebrospinal fluid and it is mainly used in cerebral MRI. In CMR, some of the major applications of the IR technique include delayed enhancement, tumor imaging, and coronary angiography.[11]

Velocity-encoded gradient echo sequences (VENC), also known as phase contrast imaging, is the CMR method of choice for blood flow quantification. This method creates a cine made up of velocity-encoded images for multiple heart cycle phases, where stationary tissue is gray and moving tissue is either black or white, depending on its direction.[13]

Blood flow quantification is performed by a software that produces time-velocity and time-flow curves.[10] This technique is used to evaluate cardiac shunts, relative flows in pulmonary and systemic circulation, and pressure gradients in valvular stenosis or regurgitation.

Different sequences can be used to perform CMR angiography. In order to assess coronary artery anomalies, the most commonly used sequences are two dimensional, segmented, gradient sequences. In order to evaluate coronary stenosis, three-dimensional techniques are used. Images can be obtained with or without intravenous contrast medium, a high T2/T1 ratio of blood acting like an intrinsic contrast for SSFP CMR angiography.[14]

Contrast-enhanced CMR techniques may be used in several situations. Myocardial viability can be assessed by performing delayed contrast enhancement (DCE), an IR GRE sequence at 10 minutes after gadolinium injection, when myocardial infarction areas characteristically display delayed enhancement. For tumor evaluation, T1 sequences are usually acquired before and immediately after gadolinium injection in order to perform a detailed characterization of the cardiac mass. Contrast enhancement can also be useful in the evaluation of coronary arteries and great vessels, with maximum intensity projections and three-dimensional vessel surface rendering as useful adjuncts.[11]

INDICATIONS

CMR offers accurate anatomic delineation and functional information and can be used in the evaluation of congenital or acquired heart diseases. Because it is a precise quantification technique, it is useful to assess ventricular volumes, function, and mass.[15] Velocity-encoded sequences may be used to measure blood flow. Gadolinium enhancement is a useful tool in the diagnostic of ischemic and non-ischemic cardiomyopathies and other, less common heart diseases.

Myocarditis

Suspected myocarditis can be evaluated by CMR, which is useful to detect edema, inflammatory hyperemia, and myocyte necrosis. Myocardium inflammation presents a hypersignal on T1 early gadolinium enhancement due to increased blood inflow. On delayed enhancement sequences, the midmyocardium will often demonstrate a patchy pattern. Edema presents a T2 hypersignal.[16] In clinical practice, this technique has impact on the therapeutic decision to indicate corticosteroid therapy or to perform endomyocardial biopsy.[17]

Cardiomyopathy

CMR is a useful method for cardiomyopathy evaluation, assessing the morphologic and functional phenotype, and also tissue characterization. By using cine and the delayed enhancement technique, CMR can accurately calculate the ejection fraction and myocardial mass. It can also detect fibrosis, scar tissue, and edema.[18] Cardiomyopathies can be widely classified into four types: hypertrophic, dilated, restrictive, and arrhythmogenic right ventricular cardiomyopathy.

CMR can diagnose hypertrophic cardiomyopathy (HCM) by demonstrating the distribution of myocardial hypertrophy and measuring wall thickness. By using VENC sequences, functional consequences including dynamic outflow obstruction and mitral valve regurgitation can be evaluated. Using delayed contrast enhancement, a patchy contrast distribution can be demonstrated in the hypertrophic areas. The extent of enhancement was correlated with sudden death risk, LV dilatation, and heart failure.[19] CMR can be also used in the follow-up of patients after percutaneous ablation or septal resection.[20]

In the diagnostic work-up of dilated cardiomyopathy (DCM), CMR may reveal impaired wall thickening, heart chamber dilation, and impaired myocardial fiber shortening. Delayed contrast enhancement is useful to differentiate primary dilated cardiomyopathies from secondary CAD cardiomyopathies. In DCM, delayed enhancement can be present or not; if it is present, it involves the subepicardium or midmyocardium, as opposed to the subendocardium enhancement with coronary distribution characteristic for ischemic cardiomyopathies.[21]

Restrictive cardiomyopathy (RCM) is characterized by myocardial wall rigidity, which does not allow relaxation

due to fibrosis or infiltration. The main features described by CMR are diastolic dysfunction and atrial dilation, while LV size and systolic function are normal.[22] The most common infiltrative causes are sarcoidosis, hemochromatosis, and amyloidosis.

In sarcoidosis, CMR demonstrates bright signal on both T2 and delayed contrast enhancement in active sarcoidosis with myocardial inflammation, while myocardial scars are visualized with DCE as hyper-signal in a patchy mid-wall or transmural areas, with non-coronary distribution.[23]

Arrhythmogenic right ventricular cardiomyopathy (ARVC) is characterized by progressive fibrous or fatty replacement involving ventricular regions, producing ventricular arrhythmias and sudden death. CMR is the imaging method of choice in ARVC evaluation, and the diagnostic criteria include severe local or global RV dysfunction, with possible LV impairment, global RV dilatation, RV or RVOT aneurysm, and fatty infiltration of RV myocardium suggested by hypersignal on T2 with fat saturation.[24]

Takotsubo cardiomyopathy is a reversible condition that mimics acute coronary syndrome. MRI is useful in its diagnosis because it can reveal not only the diffuse edema of the ventricular wall without coronary distribution but also motion abnormalities, usually akinesis in the apical and mid planes, and possible complications including left ventricular outflow tract obstruction or left ventricle thrombus.[25]

Ischemic heart disease

CMR is a useful tool used in the evaluation of ischemic heart disease, due to its ability to distinguish between the ischemic versus non-ischemic etiology of a cardiomyopathy. Delayed gadolinium enhancement can delineate a subendocardial infarction from viable myocardium and can assess the transmural extent of the infarction, which is extremely useful in characterizing myocardial viability prior to revascularization.[26] It can also evaluate possible complications after a myocardial infarction such as LV thrombus, and tt can assess myocardial viability.[4]

CONCLUSION

CMR emerged as a powerful noninvasive imaging technique in various heart diseases. It presents specific advantages over other cardiac imaging methods used in the evaluation of heart pathology. The main strengths of CMR are the absence of irradiation and its diagnostic abilities that include precise anatomical delineation, characterization of myocardial tissue, and the assessment of cardiac function by precise, reproducible measurements of blood flow and volumes.

CONFLICT OF INTEREST

Nothing to declare.

ACKNOWLEDGEMENT

This research was supported via the research grant no. 103545/2016, contract number 43/05.09.2016, entitled "High performance multimodal MRI/CT imaging platform, for applications in computational medicine, nanoparticles and hybrid imaging for the research of atherothrombotic disorders – CARDIO IMAGE" financed by the Romanian Ministry of European Funds, the Romanian Government and the European Union.

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