# Cardiac Magnetic Resonance protocol and patient preparation

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**Abstract**

*The use of magnetic resonance imaging (MRI) in cardiovascular applications has improved with the development of the hardware systems of current MRI machines: very fast activation and deactivation of gradient, radiofrequency coils with high sensitivity and high gradient amplitudes. Cardiac magnetic resonance (CMR) is an imaging technique that allows for the evaluation of the structure and function of the heart. The standard CMR protocol includes the acquisition of both structural and functional images. Structural imaging is performed using T1 and T2-weighted imaging sequences, which allow for the visualization of the heart chamber walls, tissues, and any cardiac lesions or scars. Functional imaging sequences, on the other hand, enable the assessment of the heart's contractility and its ability to pump blood effectively. The CMR protocol is a highly customizable and flexible imaging method that provides detailed information on the structure and function of the heart, as well as any cardiac pathology. CMR is a safe and non-invasive imaging technique, but requires highly skilled personnel and specialized equipment to be performed correctly.*

## INTRODUCTION

The study of the heart using magnetic resonance imaging (MRI) provides a more comprehensive understanding of its anatomy, physiology, and pathology. One of the advantages is the ability to analyze soft tissues and obtain a differential diagnosis by using different sequences in MRI scans. Additionally, dynamic imaging allows us to assess the organ's contractility and identify any potential dysfunctions. However, it is important to note that not everyone is suitable for cardiac MRI studies. It is incompatible with electronic devices and ferromagnetic implants, which are classified as MR-unsafe according to the new MRI safety nomenclature. Furthermore, successful completion of the procedure relies heavily on patient cooperation. The acquisition times are relatively long (approximately one hour for complete studies), and some individuals may have difficulty tolerating the required breath-holding periods for diagnostic image acquisition. Hence, the optimal approach to performing the procedure may vary based on the patient's cooperation level and the specific clinical question at hand.

## MATERIALS AND METHODS

One of the fundamental requirements to perform an MRI examination is the synchronization of the R wave and the RF pulse for the acquisition of the MR signal. To obtain this synchronization, a correct positioning of the electrodes is pivotal to guarantee a high amplitude of the R wave and a reduced amplitude of the T wave. Before placing the electrodes, which must be non-metallic and equipped with gel, it will be advisable to clean the skin surface with alcohol or place abrasive gel. Before starting the examination, it will be necessary to make sure that you have an optimal ECG trace (high R waves and low T waves), otherwise a new positioning of the electrodes will be needed. In combination with the ECG, respiratory gating will be used to monitor the patient. To obtain the trace of the breath is used an elastic belt placed below the ribs at the height of the diaphragm.
In clinical practice, however, many patients may not be able to hold their breath long enough and this leads to poor diagnostic images. A valid choice, which could be used to reduce acquisition times, is represented by the acquisition in apnea for at least half of the scanning time, that is, the time in which the central lines of the K-space are acquired. The central lines, in fact, correspond to the lowest spatial frequencies; Since the main information of the image is predominantly in low frequencies, it is good that motion artifacts are minimal in this acquisition phase. It is understandable, therefore, that the quality of the cardiac image increases if it is acquired with synchronism with the ECG and the retention of breath by the patient for the duration of the acquisition. Sometimes, depending on the images required and the sequences used, repeated apneas may be necessary: during each of them there will be a number of phases of the cardiac cycle in which data acquisition can be segmented.

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There are several cardiosyncronization systems: peripherical gating, ECG gating and vectorcardiographic (VCG) gating. The first one is a lesser accurate system that involve a laser applied to the patient's finger; ECG gating is most used system because it is more accurate than the previous one, and it is based on the detection of the signal by ECG, but this detection is often disturbed by the magnetic field and radiofrequency pulses, sometimes causing cardiosynchronization errors. VCG gating is a new gating technique designed to overcome the magnetohydrodynamic effect, caused by the circulation of blood protons in large vessels that create a disruptive effect. It is a more modern and more precise system that eliminates the artifacts present in the ECG by continuously recording the variations of the vectors during the cardiac cycle and making the vector sum of the various leads. It also allows you to more accurately and reliably recognize the R wave during image acquisitions (figure 1).

After obtaining signal from the ECG or VCG gating the images can be acquired. The standardized study plans defined by the Society for Cardiovascular Magnetic Resonance and the European Association of Cardiovascular Imaging are selected using SSFSE sequences based on freely-breathing reference images in trans-axial, sagittal, and coronal planes. These images, referred to as "scouts" or "localizers," can also have diagnostic relevance as they provide important information about the overall anatomy within the thoracic cage (e.g., extensions of adjacent mediastinal masses to or away from the cardiac organ). They are crucial for the initial planning of the examination.

To avoid subsequent complications, it is important to ensure that the patient is positioned at the isocenter of the magnet, where the magnetic field signal is more homogeneous, and that the signal is received from all relevant elements of the coil. In the case of AORN Cardarelli, this involves a combination of a 16-channel Anterior Array (for acquiring anterior areas) and a 32-channel integrated bed antenna (for posterior structures within the thoracic cage).

Since precise anatomical references are not available, the first acquired planes can be considered "pseudo-planes," which are necessary for the correct positioning of the subsequent standard study planes.

- **PSEUDO 2-CHAMBER PLANE**: Obtained by placing a plane on a trans-axial image that passes through the apex of the left ventricle and the mitral valve.
- **PSEUDO 4-CHAMBER PLANE**: Using the previously obtained P2C images as a reference, a plane is positioned that passes through the apex and the mitral valve (figure 2).

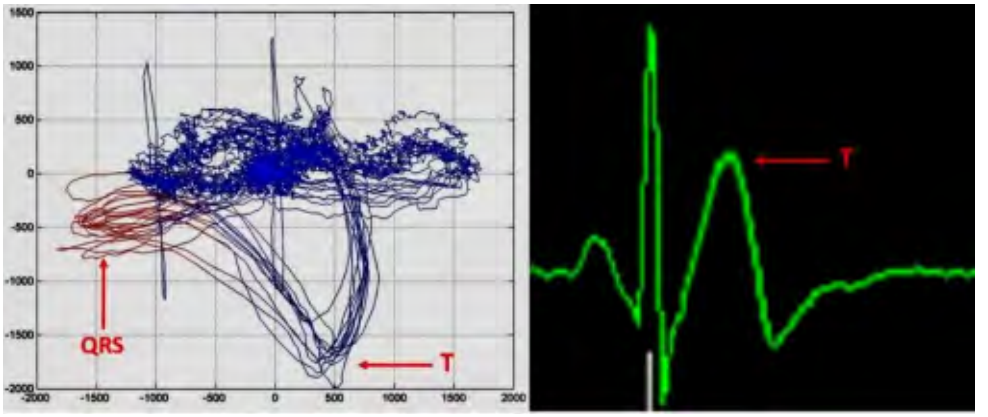


*Figure* **1**. *scheme of a vectorcardiographic (VCG) gating on the left and and ECG gating on the right.*

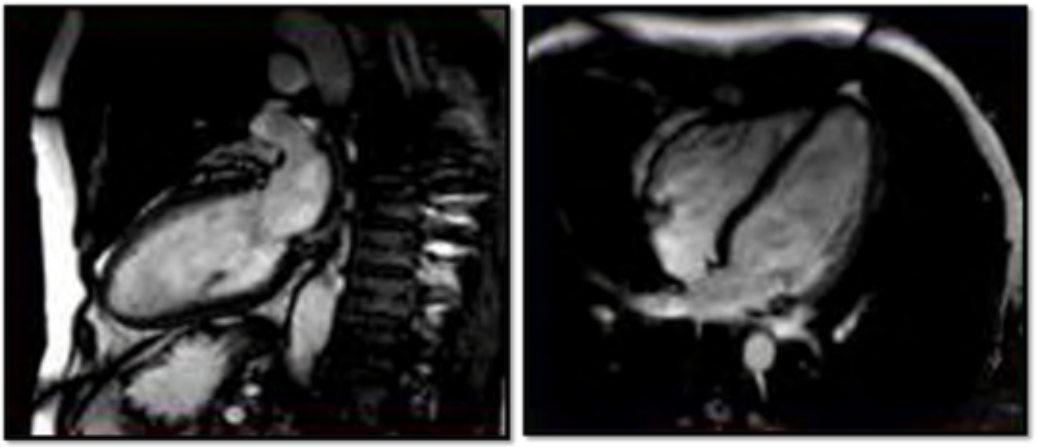

*Figure* **2.** *Left: Pseudo 2-Chamber Plane. Right: Pseudo 4-Chamber Plane.*

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After acquiring these reference images, the subsequent sequences will consider the following standard planes:

- **SHORT-AXIS 2-CHAMBER PLANE** (2CSA): Positioned perpendicular to an imaginary line connecting the true apex of the heart and the center of the mitral (for left heart study) or bicuspid valve (for right heart study), which are easily identified on the 4CP image. It is also positioned perpendicularly to the plane passing through the apex and the mitral valve on the 2CSA image.
- 4-CHAMBER PLANE (4CP): Positioned by identifying the center of the mitral valve and the apex of the right ventricle. On the 2CSA image, it follows a plane passing through the apex and the mitral valve.
- **LONG-AXIS 2-CHAMBER PLANE**: Positioned with reference to the 4CP and short-axis planes. The plane intersects the center of the cardiac valve and the true apex in combination with the inferior and anterior walls of the left ventricle on the short-axis 2-chamber plane.
- **3-CHAMBER PLANE:** The plane of the 3-chamber sequence passes through the apex and the mitral valve on the 2CSA plane. On the short-axis plane, it intersects the aortic valve and the posterior wall (figure 3).

The cardiac MRI study protocol have specific sequences for the study of cardiac anatomy:

- **FIESTA Sequences:** These sequences are primarily used for the study of myocardial motion and contractility, capable of documenting the various phases of the cardiac cycle over time (early-late systole, early-late diastole). Through these sequences, important study indices can be obtained (stroke volume, ejection fraction, ventricular mass and volume). They are also known as bright blood sequences, as the blood signal within the cardiac chambers and vessels appears hyperintense, allowing for the visualization of suspected thrombi which, in contrast, appear hypointense (Figure 4). Global cine analysis is performed using dedicated post-acquisition software. End-diastolic and end-systolic volumes, as well as ventricular mass, can be easily calculated from short-axis images by tracing the endocardial and epicardial borders in the end-systolic and end-diastolic phases.
- **BLACK BLOOD (BB) Sequences**: These are fast sequences that minimize respiratory and motion artifacts. The Signal-to-Noise Ratio translates into lower spatial resolution. They utilize various weightings: T1, T2, and proton density (DP). T1-weighted sequences are useful for improved anatomical detail, while T2 and DP-weighted sequences aid in better tissue characterization. BB sequences are particularly valuable in studying fibrosis, necrosis, and assessing ischemic damage (Figure 5).

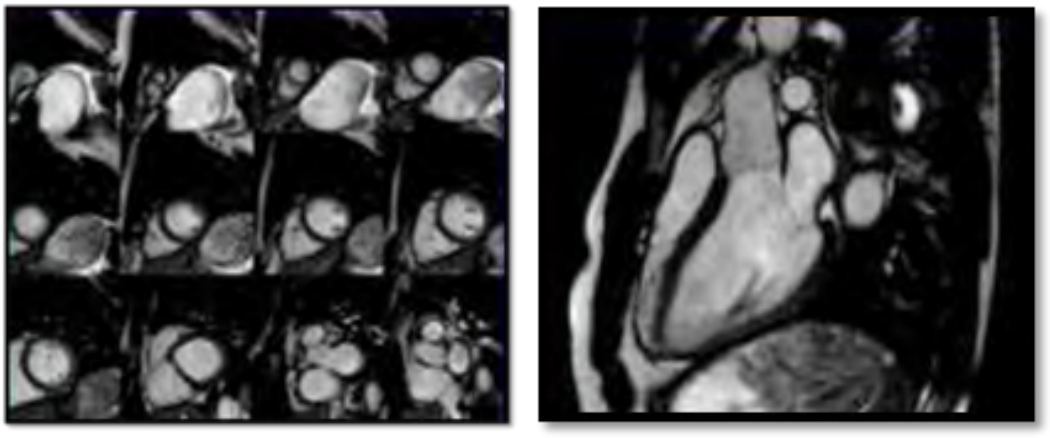

***Figure 3**. Short Axis Plane on the left; 3-Chambers Plane on the right*

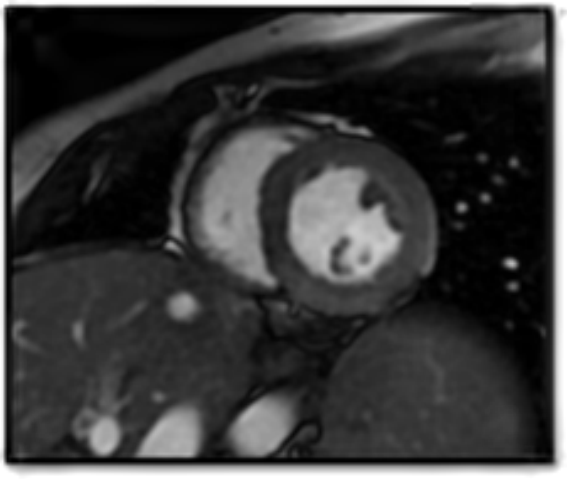

***Figure 4**. FIESTA image in short-axis 2-chamber view*

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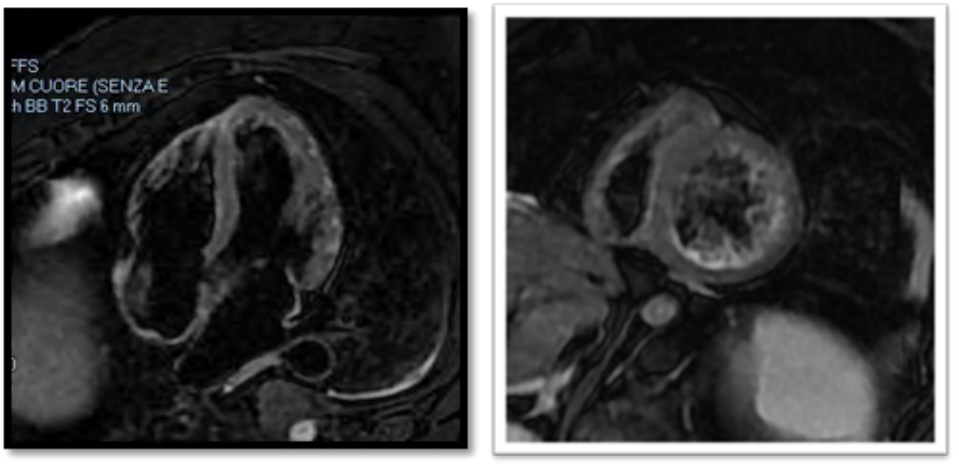


*Figure 5. Fat sat Black Blood T2 image in 4-chamber view on the left; Black Blood on short axis view*

- PERFUSION: It involves the dynamic study of the time-dependent distribution of the contrast agent bolus during its first pass through the myocardium. This is achieved using a gradient echo sequence with T1 weighting and high temporal resolution, typically acquiring a minimum of 3-5 images per cardiac cycle. The acquisition is usually performed in the short-axis 2-chamber view at three levels of the left ventricle, as defined by the guidelines of the American Association of MRI-Cardiovascular Imaging, along an axis from the mitral valve plane to the apex of the left ventricle, during breath-hold expiration. High flow rates of 3-5 ml/s are used. Myocardial perfusion defects appear as regions of no enhancement in the myocardial tissue during the first pass of the contrast agent through the myocardium (Figure 6).
- **VITALITY STUDY, CINE IR, and 2D MDE RR:** With the CINE IR sequence, we determine the inversion time (TI) that nullifies the signal from healthy myocardium. This value is then manually set in the "Prep Time" field of the 2D MDE RR sequence, a gradient echo acquired at 20 minutes (or slightly longer) after the administration of the contrast agent, typically in the short-axis view. This allows the identification of pathological myocardial tissue, characterized by a slower wash-out. Areas of marked enhancement may indicate evolved fibrotic tissue resulting from myocardial infarction. The characterization is even more pronounced when suppressing the signal from healthy tissue by setting the correct TI value (Figure 7).

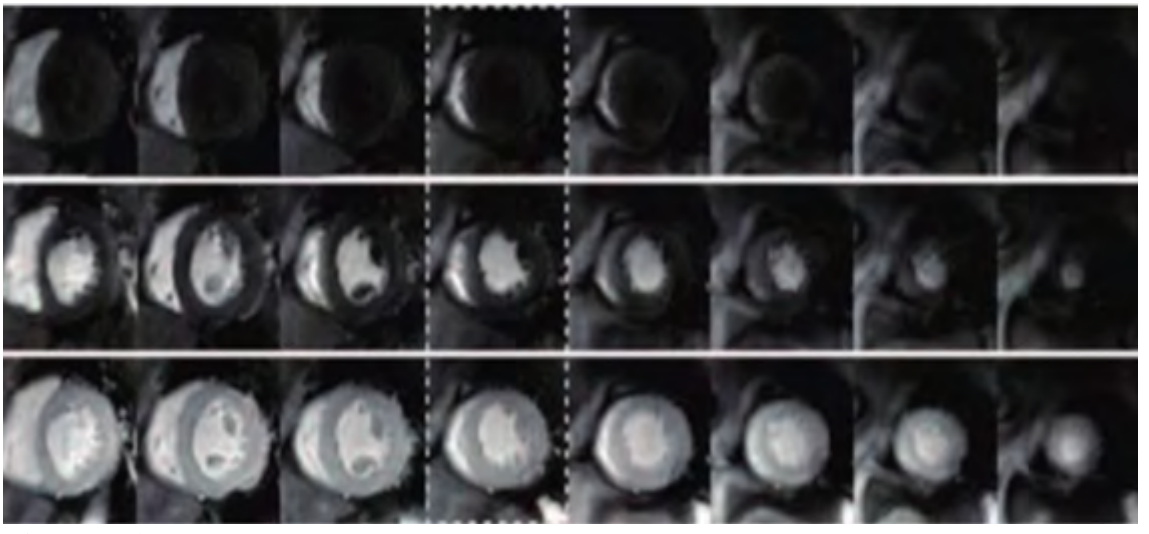

*Figure 6. Perfusion sequence*

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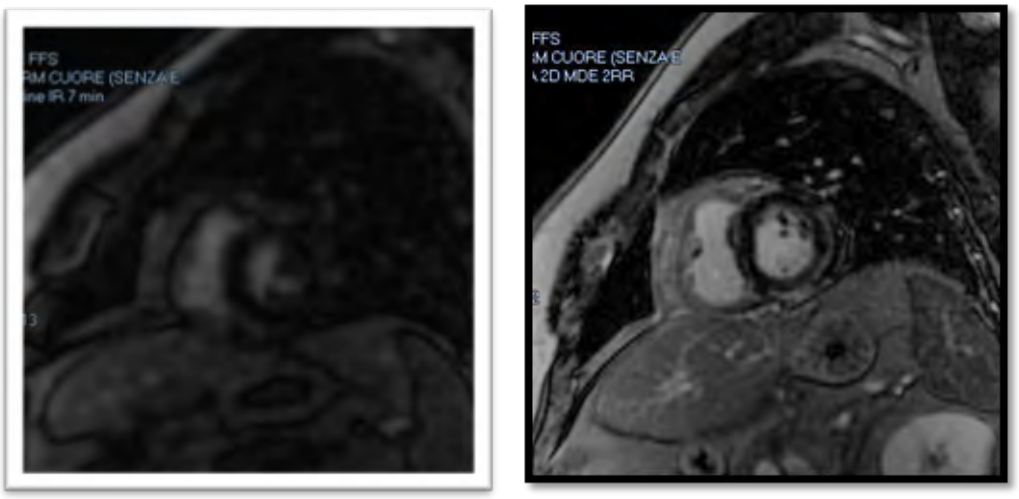


*Figure 7. CINE IR Image showing myocardial signal nullification; 2D MDE RR Image acquired with manually set TI to achieve suppression of healthy myocardium*

Improving the quality of acquired images

There are several parameters to consider if the goal is to obtain high-quality images. The Freq. FOV field allows us to adjust the FOV amplitude. A larger FOV avoids folding artifacts and increases the image signal to noise ratio by increasing the voxel size. The Slice Thickness field allows us to modify the layer thickness: thinner slices increase spatial resolution. Increasing the values of NEX (number of excitations), Frequency, and Phase enhances the overall image quality. Specifically, the CMR study protocol uses parameters that are not typically used in other body MRI protocols. In this regard, it is essential to introduce the concept of R-R Interval: when considered together, the P, Q, R, S, and T waves form the so-called PQRST complex. The interval between two PQRST complexes is defined as the "R-R Interval." The R-R interval corresponds to one cardiac cycle and is also the time interval during which cardiac images are acquired in resonance. Acting on the RR Interval field allows you to determine how many images to acquire during the RR interval. The best images are acquired during the "quiescent" or "still heart" phase: the lower this parameter, the better the image quality. Ideally, a single image should be acquired per RR interval. The Trigger Delay indicates the time after an R wave when image acquisition begins. Choose the optimal value based on the phase to be captured: Systolic (0-50 ms) / Diastolic (150-200 ms). The Trigger Window parameter indicates the tolerance for arrhythmias: the lower the value, the better the quality of the acquired images.

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