



## Comprehensive guide to cardiac MRI planning & sequences

**Balwinder Kumar Thapa**

Assistant Professor, Department of Radiology & Imaging Technology, University School of Allied Health Sciences, Rayat Bahra University, Mohali, Punjab, India

### Abstract

In cardiac magnetic resonance imaging (CMRI), the diagnostic radiologists/technologists have a significant challenge because to the intricate movement of the heart during contraction. The main goals of cardiac magnetic resonance imaging (CMRI) are to obtain detailed information about the anatomy and physiology of the heart. In cardiac MRI, the procedures and planning can be used to get pertinent morphologic and physiologic data in three planes; short axes (SA), horizontal long axes (HLA) and vertical long axes (VLA) <sup>[1, 4]</sup>.

**Keywords:** Myocardial perfusion, late gadolinium enhancement (LGE), black-blood methods, and ventricular function

### Introduction

A group of magnetic resonance imaging (MRI) techniques used to evaluate cardiac morphology, cardiac perfusion, tissue characterization, cardiac artery disease, and ventricular function are together referred to as cardiovascular magnetic resonance imaging (CMRI). MRI is a non-invasive, radiation-free method that can be used to assess treatment outcomes over an extended period of time as well as track the course of a diseases.

Heart and respiratory movements present unique hurdles for CMRI compared to MRI of other body parts. Consequently, in order to overcome motion artifacts in CMRI, synchronous cardiac and respiratory gating or breath-holding approaches are needed.

The fundamentals of MRI are covered in this article, along with an introduction to CMRI methods that can be improved for better clinical assessment. The detailed images of CMRI provides can be used by clinicians to aid in diagnosis and treatment planning of the heart <sup>[5, 7]</sup>.

**Aim and objective:** This article aims to provide a comprehensive overview of the planning process and essential sequences involved in cardiac MRI. The study was done in a tertiary Health Care Centre in North India.

**Morphology:** Cardiac MRI is a powerful diagnostic tool used to evaluate the anatomy, function, and blood flow of the heart.

### The overview of the Morphology of Cardiac MRI

- 1. Chambers of the Heart:** The study left atrium, left ventricle, right atrium, and right ventricle; their size, shape, and function.
- 2. Myocardium:** The muscle tissue of the heart, is examined for signs of damage, inflammation, or abnormalities such as myocardial infarction, myocarditis, or cardiomyopathy.
- 3. Valves:** The tricuspid valve, pulmonary valve, mitral valve, and aortic valve. It can assess valve morphology, function, and any abnormalities such as stenosis or regurgitation.

- 4. Pericardium:** The sac surrounding the heart, can also be evaluated using cardiac MRI. It can detect pericardial effusion (fluid around the heart).
- 5. Blood flow:** Cardiac MRI can assess blood flow through the heart and major vessels.
- 6. Scar tissue and fibrosis:** MRI is particularly useful for detecting scar tissue and fibrosis within the myocardium.
- 7. Function:** Ejection fraction, or the proportion of blood pumped out of the heart with each contraction, is one of the factors that cardiac magnetic resonance imaging (CMRI) offers dynamic information.
- 8. Vascular structures:** MRI can also visualize major vascular structures related to the heart, such as the aorta and pulmonary arteries, providing information about their size, morphology, and any associated abnormalities.
- 9. Tissue characterization:** MRI techniques, such as T1 and T2 mapping, can characterize tissue properties and to differentiate between various pathologies and normal tissue <sup>[8, 10]</sup>.

### Methods and materials

CMRI study was performed using an MRI system operating at a static magnetic field strength of 3.0T MRI machine used for cardiac procedure:

#### “Mri-Ingenuis 3.0t Philips”

Key features of the Ingenuis 3.0T Philips:

**D Stream:** This digital broadband architecture delivers high-quality images and extraordinary speed. Using channel-independent RF technology, it offers up to 40% higher Signal-to-Noise Ratio (SNR) and improved throughput.

**In-Bore experience:** During the MRI exam, this feature provides patients with a soothing, entertaining visual or

auditory distraction. Through the headphones, voice assistance can be provided, assisting patients in calming down and maintaining stillness for improved image quality.

**Elevate clinical performance:** Because of digitization at the patient, dStream digital broadband technology offers up to 40% higher SNR. This enables you to successfully complete increasingly complex neuro checks as well as the rapidly expanding body and heart exams.

The system also uses adaptive software that automatically plans scanning geometries based on your authenticated scanning preferences.

### Specifications

Philips Magnetic Resonance Ingenia 3.0T with Omega gradients with Omega HP gradients:

**Table 1:** Magnet Parameters of "MRI-Ingénias 3.0T Philips"

Magnet Parameters	
Field strength	3.0 T
Frequency	127.7 MHz
Design of magnet	light weight and compressed
Magnet length, width and height	1.62 x 1.88 x 2.29 meters
Magnet weight with cryogen	4600 kg
Magnet length	1.62 m
Open bore diameter including shim, gradient & QBC)	70 cm
Maximum Focal of of vision Field of view (FOV)	55 cm
(5 G) axial x radial fringe field	3.05 x 4.95 m
Axial x radial fringe field 1 G	4.20 x 7.25 m
Stability over time	< 0.1 ppm/hr is guaranteed. Average: 0.001 ppm/hour

### Basic anatomy of the heart

**The heart is made up of four chambers:** Blood is collected in the two top chambers, or atrium.

**Ventricles:** The heart's two lower chambers (where blood is ejected).

The septum, a muscular wall, divides the left ventricle and atria from the right ventricle and atria.

### The wall of the heart made up of three layers of tissue:

**Epicardium:** Mostly connective tissue-based protecting layer.

**Myocardium:** the heart's muscles mass.

**Endocardium:** covers the heart's interior and shields its chambers and valves.

The pericardium, a thin layer of heart tissue, encircles these layers.

### The valves

The four heart valves work together to restrict blood flow in a one direction:

**Aortic valve:** located between the left ventricle and the aorta.

**The mitral valve:** located between the left atrium and the left ventricle.

**The pulmonary valve:** located between the right ventricle and the pulmonary artery. The tricuspid valve is located between the right ventricle and the right atrium <sup>[11]</sup>.

### How the heart functions

The heart's left and right sides are work together. Blood that has deoxygenated is received by the right side of the heart and sent to the lungs, whereas blood from the left side of the heart is received by the lung and circulated throughout the body. A regular heartbeat is produced by the successive contraction and relaxation of the ventricles and atria.

**Right side:** The largest veins in the body, the superior and inferior vena cava, supply the right atrium with blood that has been deoxygenated.

Blood enters the right ventricle as the right atrium contracts. When the right ventricle is full, it contracts and sends blood via the pulmonary artery to the lungs, where it absorbs oxygen and exhales carbon dioxide.

**Left side:** The pulmonary vein returns freshly oxygenated blood to the left atrium. Blood is forced into the left ventricle by the left atrium's contraction.

When the left ventricle fills up, it contracts, rerouting blood flow via the aorta to the body.

Every heartbeat can be divided into two components that is diastole and systole;

**Diastole:** the atria and ventricles relax and fill with blood.

**Systole:** The ventricles constrict (ventricular systole) and force blood out of the heart when the atria start to relax. Atrial systole is the term for this process <sup>[12, 13]</sup>.

### Clinical conditions

#### Cardiac MRI in ischemic heart disease

Acute Coronary Syndrome

Viability

Scar

Anomalous Coronary Arteries

#### Cardiac MR in cardiomyopathies (non-ischemic)

Acute myocarditis

Cardiomyopathies of hypertrophies

Noncompaction of the ventricles

Heart related Arrhythmias

Sarcoidosis of heart

Myocardial siderosis

#### Cardiac MR intracardiac and extracardiac structure:

Heart masses

Benign tumors

Cancerous growths

Thrombus

Pericardial conditions

Vascular structure

Aorta

Pulmonary artery

Pulmonary veins <sup>[14, 17]</sup>

### Planning and Sequences in Cardiac MRI

#### Planning and Sequences:

ECG Gated technique (avoid image blur & cardiac motion artifact).

**Two types of techniques**

1. Dark blood technique:
2. Bright blood technique.

**1. Dark Blood Technique:** Spin Echo (blood appear black & fat is white). TSE, FSE, HASTE & Double-IR-FSE etc. are the Spin Echo sequences <sup>[18]</sup>.

**2. Bright Blood Technique:** GE Sequences (both blood & fat appear white). FLASH, SSFP, & Velocity Mapping etc are the Gradient (GE) sequences. (Dark blood sequences obtain anatomical information & bright blood show functional abnormalities).

**Pulse sequences:** In cardiac imaging, pulse sequences fall into two primary categories: black-blood techniques and bright-blood techniques. Heart sequences using gradient echo are typically considered bright-blood techniques, while cardiac sequences using spin echo (SE) are typically considered black-blood techniques.

**SSFP sequence:** Cine cardiac MR imaging now relies on a set of sequences called Steady State Free Precession (SSFP) as its foundation. True FISP, FIESTA, and Fast Field Echo (FFE). A variation on gradient echo imaging called SSFP yields blood pictures with a high degree of contrast between the myocardial and the blood in the heart (blood pool) <sup>[19]</sup>.

**IR sequence:** Inversion Recovery (IR) pulses are utilized to counteract the signal from a specific tissue in order to emphasize adjacent disease. This method is commonly used to null the signal from the normal myocardium during delayed enhanced imaging <sup>[20]</sup>.

**Routine Cardiac MRI Protocol Philips Ingenia 3T**

**Table 2:** MRI Protocol of Philips Ingenia-3T. Routine, Inversion Recovery (IR), Steady State Free Precession (SSFP), Dynamic\_TFE Multiplane Sequences for earlier and late contrast enhance gadolinium (GEO)

Localizer	
<b>Pulse sequences:</b>	
BB_SSH_Rtrig -----	TRA
sBTfE_bh-----	2CH
sBTfE_bh-----	4CH
sBTfE_bh-----	SA
<b>INVERSION RECOVERY (IR)</b>	
STIR-----	SA
STIR-----	HLA
STIR-----	VLA
<b>STEADY STATE FREE PRECESSION (SSFP)</b>	
CINE -----	2CH (VLA)
CINE -----	4CH (HLA)
CINE -----	3CH (LVOT/RVOT)
CINE -----	4CH (SA)
<b>DYN_TFE MULTIPLANE -----GEO</b>	
EGE-----	SA
EGE-----	HLA
EGE-----	VLA
<b>IR_TFE-LL-2b-----GEO</b>	
LGE-----	SA
LGE-----	HLA
LGE-----	VLA

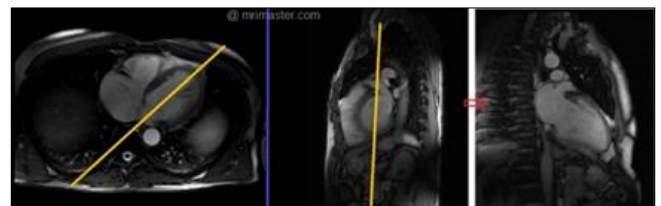
**Steps of planning**

Due to complex anatomy of heart and vascular structures and oblique position in body, to visualize the specific structures specific planes are acquired as stated below Some BASIC IMAGING PLANES taken in cardiac MRI examination are:

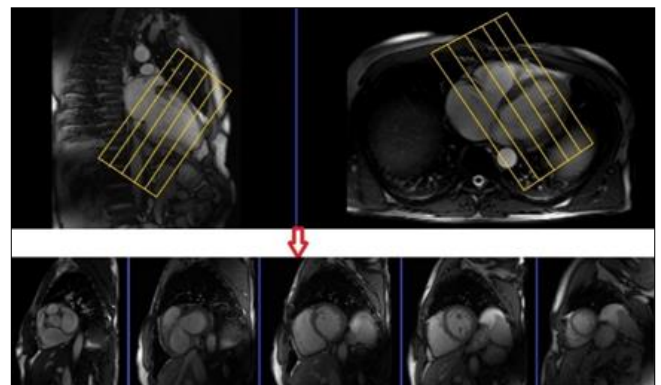
- STEP 1. Scouts and planning views
- STEP 2. Short axis (SAX) stacks acquisition (VLA, HLA)
- STEP 3. Long axis (LAX) views acquisition
  - 2 CH (VLA, HLA) View
  - 3 CH (RVOT OR LVOT) View
  - 4 CH (VLA, HLA and SA) View

**Basic cardiac view**

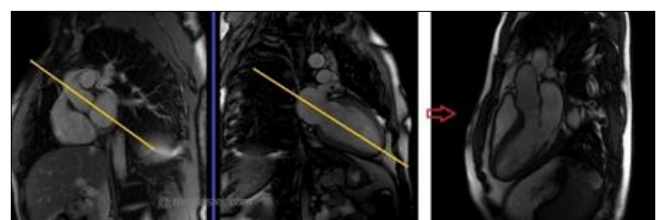
Scout for localization in 3 plane axial coronal and sagittal T1 or T2W of entire chest that include kidneys and liver <sup>[21, 24]</sup>.



**Fig 1:** 2 Chambers Planning



**Fig 2:** SHORT AXIS Planning <sup>[25]</sup>



**Fig 3:** 3 CH/LVOT Planning <sup>[26]</sup>

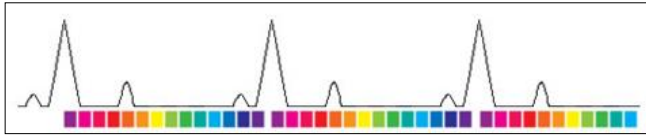
**Cine imaging**

Cine pictures are brief films that show the action of the heart at various points during the cardiac cycle. Cine images are obtained by means of segmented imaging that is triggered by an ECG.

Segmented acquisition (cine) is the process of dividing the cardiac cycle into many segments, or frames, to provide a set of images that can be viewed as a movie <sup>[27, 28]</sup>.

The cardiac cycle typically consists of 10 to 20 parts, depending on the heart rate. The ECG's R wave initiates it, and the following R wave ends it. Because each image in a movie is often made up of data gathered across multiple

heartbeats, depending on the sequence, a movie can be seen in breath holds of 10 to 20 seconds. [29].



Studying cardiac function, valve function, and blood flow via the heart can be greatly aided by these images. Throughout the cardiac cycle, the myocardium thickens and contracts; any anomaly in this wall motion suggests a myocardial condition, such as ischemia or an infarct [30].

**Cardiac Imaging**

**Table 3:** 2 & 4 Chamber basic view of Pulse cardiac MRI with pulse sequences

Pulse Sequences	
BB_SSH_Rtrig	-----TRA
sBTfE_bh	-----2CH
sBTfE_bh	-----4CH
sBTfE_bh	-----SA

**Table 4:** SA, HLA and VLA view of Inversion recovery (IR) of cardiac MRI

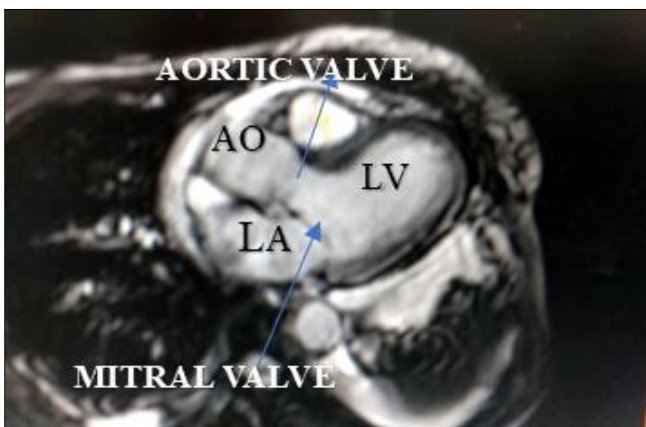
Inversion Recovery (IR)	
STIR	-----HLA
STIR	-----VLA
STIR	-----SA

The Inversion Recovery (IR) was evidently Cardiomyopathy in the heart's vertical long axis (VLA). This illness damages the heart muscle, making it harder for the heart to circulate blood throughout the body. Cardiomyopathy may be the cause of heart failure.

**Steady state free precession (SSFP)**

**Table 5:** 2CH (VLA), 4CH (HLA), 3CH (LVOT/RVOT) and 4CH(SA) view of Cine Sequences of Cardiac MRI

Cine Sequences	
CINE	-----2CH (VLA)
CINE	-----4CH (HLA)
CINE	-----3CH(LVOT/RVOT)
CINE	-----4CH (SA)



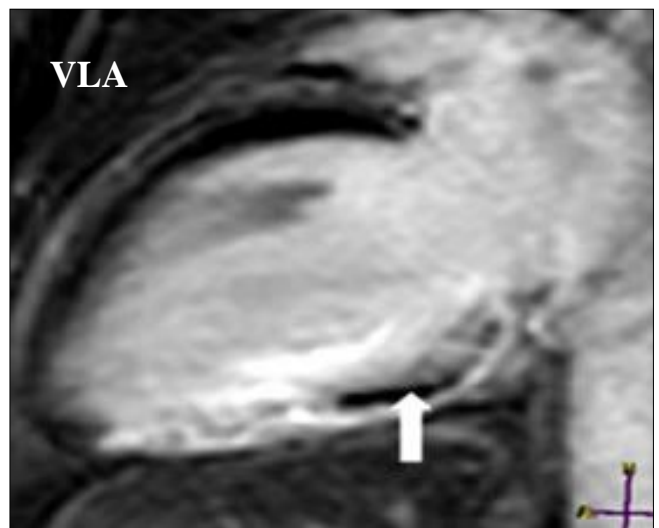
**Fig 4:** 3CH (Chamber) left ventricle outflow tract (LVOT), Cine-2 Sequence [31]

**Contrast agents**

Gadolinium, the contrast agent used in MR angiography and tissue enhancement, is not nephrotoxic, but patients suffering from renal failure should use caution when administering it due to the possibility of nephrogenic systemic fibrosis, an uncommon but dangerous adverse effect. Before contrast is given, a pre-procedure creatinine level and creatinine clearance need to be completed [32].

**Table 6:** HLA, VLA and SA view of Early Gadolinium Enhancement (EGE) of cardiac MRI [33]

Early Gadolinium Enhancement (EGE)	
EGE	-----HLA
EGE	-----VLA
EGE	-----SA



**Fig 5:** 2CH(Chamber) vertical long axis (VLA) Earlier Gadolinium enhancement (EGE) contrast study shows scar like pattern of cardiac tissue on left ventricle (LV) [34]

**Table 7:** HLA, VLA and SA view of Late Gadolinium Enhancement (LGE) of cardiac MRI [35]

Late Gadolinium Enhancement (LGE)	
LGE	-----HLA
LGE	-----VLA
LGE	-----SA

These are gradient-echo, T1 weighted sequences. Ten minutes following the delivery of gadolinium contrast, image capture is carried out.

There is a delayed gadolinium contrast wash off in focal myocardial fibrosis. A myocardial scar, and thus an evolving myocardial infarction, is indicated by a hyperenhancement.

To increase contrast between the surrounding myocardium and the fibrosis, an additional inversion pulse is typically applied [36, 38].

**Results**

Cardiac MRI Planning and Sequences would ideally contribute to the scientific understanding and advancements in the field of cardiac imaging. The Advancements in imaging techniques is improved cardiac MRI planning methods and sequences, potentially enhancing the quality and accuracy of cardiac imaging.

The above study is showing clearly visibility of Cardiac myopathy, scaring of heart tissue, left ventricle outflow (LVOT) and function of heart.

This research could involve comparative studies with existing cardiac imaging methods, highlighting the advantages of the proposed planning and sequences in comparison to established techniques<sup>[39]</sup>.

### Discussion

It is very technical challenges during the cardiac imaging study, because the heart is not in the same position in all the patients. Cardiac MRI sequences are entirely depended upon the planning. So, it is necessary to make the heart in true anatomical position by using routine pulse sequences and gradient sequences in both dark blood technique and bright blood technique. Once the heart is in proper anatomical position, then take three planes of heart; the true horizontal long axis (HLA), the true vertical long axis (VLA) and the true sort axis (SA).

In the above study by taking axial cut of the body we get 4 channel study for 4 chambers of heart. Right atrium (RA), right ventricle (RV), left atrium (LA) and left ventricle (LV). From left ventricle and left atrium, we get 2 chambers with mitral valve. And same on the right side with tricuspid valve. From the two chambers of either side, we get sort axis (SA), the other two plane HLA and VLA, all in true position. The three-plane position are saved. The saved position used for cine sequences, inversion recovery, earlier gadolinium and late gadolinium sequences. The study indicates cardiac myopathy, scaring of heart tissue and left ventricle outflow (LVOT) of heart<sup>[40, 41]</sup>.

### Conclusion

In conclusion, cardiac magnetic resonance imaging (CMRI) stands as a pivotal diagnostic tool in the field of cardiovascular medicine, offering a non-invasive and overall assessment of the heart's structure and function. This advanced imaging modality provides detailed anatomical and functional information, contributing outstandingly to the diagnosis, treatment planning, and ongoing management of various cardiac conditions.

The non-invasive nature of cardiac MRI reduces patient risk and discomfort compared to invasive procedures, making it a preferred choice in many clinical scenarios. Its role in research and education further advances our understanding of cardiovascular diseases, fostering continuous improvement in diagnostic techniques and treatment strategies<sup>[42]</sup>.

### References

- Ginat DT, Fong MW, Tuttle DJ, Hobbs SK, Vyas RC. Cardiac imaging: Part 1, MR pulse sequences, imaging planes, and basic anatomy. *AJR Am J Roentgenol*,2011;197(4):808-15. doi: 10.2214/AJR.10.7231. PMID: 21940567.
- Gaba RC, Carlos RC, Weadock WJ, Reddy GP, Sneider MB, Cascade PN. Cardiovascular MR imaging: technique optimization and detection of disease in clinical practice. *Radiographics*,2002;22(6):e6. doi: 10.1148/rg.e6. PMID: 12432131.
- Reeder SB, Du YP, Lima JA, Bluemke DA. Advanced cardiac MR imaging of ischemic heart disease. *Radiographics*,2001;21(4):1047-74. doi: 10.1148/radiographics.21.4.g01jl281047. PMID: 11452080
- Boxt LM. Cardiac MR imaging: a guide for the beginner. *Radiographics*,1999;19(4):1009-25, discussion 1026-8. doi: 10.1148/radiographics.19.4.g99jl161009. PMID: 10464806.
- Pennell DJ, Sechtem UP, Higgins CB, Manning WJ, Pohost GM, Rademakers FE, *et al*. European Society of cardiology; Soceity for Cardiovascular Magnetic Resonance. Clinical indications for cardiovascular magnetic resonance (CMR): Consensus Panel report. *J Cardiovasc Magn Reson*,2004;6(4):727-65. doi: 10.1081/jcmr-200038581. PMID: 15646878.
- Tseng WY, Su MY, Tseng YH. Introduction to Cardiovascular Magnetic Resonance: Technical Principles and Clinical Applications. *Acta Cardiol Sin*,2016;32(2):129-44. Doi: 10.6515/acs20150616a. PMID: 27122944; PMCID: PMC4816912
- Lee E, Ibrahim ES, Parwani P, Bhave N, Stojanovska J. Practical guide to evaluating myocardial disease by cardiac MRI. *American Journal of Roentgenology*,2020;214(3):546-56.
- Bioletto F, Prencipe N, Berton AM, Bona C, Parasiliti-Caprino M, Faletti R, *et al*. MRI assessment of cardiac function and morphology in adult patients with growth hormone deficiency: a systematic review and meta-analysis. *Frontiers in Endocrinology*,2022;10(13):910575.
- Hamirani YS, Kramer CM. Cardiac MRI Assessment of Myocardial Perfusion. *Future Cardiology*,2014;10(3):349–358. <https://doi.org/10.2217/fca.14.18>
- Martin ET, Coman JA, Shellock FG, Pulling CC, Fair R, Jenkins K. Magnetic resonance imaging and cardiac pacemaker safety at 1.5-Tesla. *J Am Coll Cardiol*,2004;43(7):1315-24. Doi: 10.1016/j.jacc.2003.12.016. PMID: 15063447.
- Ardura-Garcia C, Kohlbrenner D, Cruz J. Shape your career: opportunities for Early Career Members in 2022 and the experience of applying for an ERS fellowship. *Breathe (Sheff)*,2022;18(1):210218. Doi: 10.1183/20734735.0218-2021. Epub 2021 Mar 8. PMID: 35295548; PMCID: PMC8919781.
- Hinton RB, Yutzey KE. Heart valve structure and function in development and disease. *Annu Rev Physiol*,2011;73:29-46. Doi: 10.1146/annurev-physiol-012110-142145. PMID: 20809794; PMCID: PMC4209403.
- Buckberg GD, Nanda NC, Nguyen C, Kocica MJ. What Is the Heart? Anatomy, Function, Pathophysiology, and Misconceptions. *J Cardiovasc Dev Dis*,2018;5(2):33. Doi: 10.3390/jcdd5020033. PMID: 29867011; PMCID: PMC6023278.
- Kolentinis M, Le M, Nagel E, Puntmann VO. Contemporary Cardiac MRI in Chronic Coronary Artery Disease. *Eur Cardiol*,2020;15:e50. Doi: 10.15420/ecr.2019.17. PMID: 32612708; PMCID: PMC7312615.
- Adhikary D, Barman S, Ranjan R, Stone H. A Systematic Review of Major Cardiovascular Risk Factors: A Growing Global Health Concern. *Cureus*,2022;14(10):e30119. Doi:

- 10.7759/cureus.30119. PMID: 36381818; PMCID: PMC9644238.
16. Antonopoulos AS, Vrettos A, Androulakis E, Kamperou C, Vlachopoulos C, Tsioufis K, *et al.* Cardiac magnetic resonance imaging of pericardial diseases: a comprehensive guide. *Eur Heart J Cardiovasc Imaging*,2023;24(8):983-998. Doi: 10.1093/ehjci/jead092. Erratum in: *Eur Heart J Cardiovasc Imaging*. 2024 Feb 22;25(3):e104. Doi: 10.1093/ehjci/jead345. PMID: 37207354.
  17. Wang TKM, Ayoub C, Chetrit M, Kwon DH, Jellis CL, Cremer PC, *et al.* Cardiac Magnetic Resonance Imaging Techniques and Applications for Pericardial Diseases. *Circ Cardiovasc Imaging*,2022;15(7):e014283. doi: 10.1161/CIRCIMAGING.122.014283. Epub 2022 Jul 5. PMID: 35861978.
  18. Edelman RR, Leloudas N, Pang J, Koktzoglou I. Dark blood cardiovascular magnetic resonance of the heart, great vessels, and lungs using electrocardiographic-gated three-dimensional unbalanced steady-state free precession. *J Cardiovasc Magn Reson*,2021;23(1):127. Doi: 10.1186/s12968-021-00808-2. PMID: 34724939; PMCID: PMC8559409.
  19. Miller KL. FMRI using balanced steady-state free precession (SSFP). *Neuroimage*,2012;62(2):713-9. Doi: 10.1016/j.neuroimage.2011.10.040. Epub 2011 Oct 20. PMID: 22036996; PMCID: PMC3398389.
  20. Zhang Q, Li Q, Zhang J, Zhang Y. Double inversion recovery magnetic resonance imaging (MRI) in the preoperative evaluation of hippocampal sclerosis: correlation with volumetric measurement and proton magnetic resonance spectroscopy (<sup>1</sup>H MRS). *J Comput Assist Tomogr*,2011;35(3):406-10. doi: 10.1097/RCT.0b013e318219c2b6. PMID: 21586939.
  21. Kim PK, Hong YJ, Im DJ, Suh YJ, Park CH, Kim JY, *et al.* Myocardial T1 and T2 Mapping: Techniques and Clinical Applications. *Korean J Radiol*,2017;18(1):113-131. Doi: 10.3348/kjr.2017.18.1.113. Epub 2017 Jan 5. PMID: 28096723; PMCID: PMC5240500
  22. Amano Y, Yanagisawa F, Tachi M, Asai K, Suzuki Y, Hashimoto H, *et al.* Three-dimensional Cardiac MR Imaging: Related Techniques and Clinical Applications. *Magn Reson Med Sci*,2017;16(3):183-189. Doi: 10.2463/mrms.rev.2016-0116. Epub 2017 Feb 16. PMID: 28202854; PMCID: PMC5600024.
  23. Blanken CPS, Farag ES, Boekholdt SM, Leiner T, Kluin J, Nederveen AJ, *et al.* Advanced cardiac MRI techniques for evaluation of left-sided valvular heart disease. *J Magn Reson Imaging*,2018;48(2):318-329. Doi: 10.1002/jmri.26204. PMID: 30134000; PMCID: PMC6667896.
  24. Marchesseau S, Ho JX, Totman JJ. Influence of the short-axis cine acquisition protocol on the cardiac function evaluation: A reproducibility study. *Eur J Radiol Open*,2016;3:60-6. doi: 10.1016/j.ejro.2016.03.003. PMID: 27069981; PMCID: PMC4811847.
  25. Chitiboi T, Kanski M, Tautz L, Hennemuth A, Halpern D, Sherrid M, *et al.* Analysis of three-chamber view conventional and tagged cine MRI in patients with suspected hypertrophic cardiomyopathy. *MAGMA*,2020;33(5):613-626. Doi:10.1007/s10334-020-00836-6. Epub 2020 Mar 9. PMID: 32152793; PMCID: PMC7484000.
  26. Blansit K, Retson T, Masutani E, Bahrami N, Hsiao A. Deep Learning-based Prescription of Cardiac MRI Planes. *Radiology: Artificial Intelligence*,2019;1(6):e180069. doi:10.1148/ryai.2019180069
  27. Mahapatra D. Cardiac image segmentation from cine cardiac MRI using graph cuts and shape priors. *J Digit Imaging*,2013;26(4):721-30. Doi: 10.1007/s10278-012-9548-5. PMID: 23319109; PMCID: PMC3705018.
  28. Menchón-Lara RM, Simmross-Wattenberg F, Casaseca-de-la-Higuera P, Martín-Fernández M, Alberola-López C. Reconstruction techniques for cardiac cine MRI. *Insights Imaging*. 2019 Sep 23;10(1):100. Doi:10.1186/s13244-019-0754-2. PMID: 31549235; PMCID: PMC6757088.
  29. Rasul S, Calabretta R. Impact of ECG gating methods on the assessment of left ventricular cardiac function using PET/MRI. *Journal of Nuclear Cardiology*,2023;30(3):1061-4.
  30. Rasul S, Calabretta R. Impact of ECG gating methods on the assessment of left ventricular cardiac function using PET/MRI. *J Nucl Cardiol*,2023;30(3):1061-1064. Doi: 10.1007/s12350-022-03177-0. Epub 2022 Dec 29. PMID: 36581772; PMCID: PMC10261213.1
  31. Sherrid MV, Männer J, Swistel DG, Olivotto I, Halpern DG. On the Cardiac Loop and its Failing: Left Ventricular Outflow Tract Obstruction. *J Am Heart Assoc*,2020;9(3):e014857. Doi: 10.1161/JAHA.119.014857. Epub 2020 Jan 28. PMID: 31986992; PMCID: PMC7033877.
  32. Uhlig J, Al-Bourini O, Salgado R, Francone M, Vliegthart R, Bremerich J, *et al.* Gadolinium-based Contrast Agents for Cardiac MRI: Use of Linear and Macrocyclic Agents with Associated Safety Profile from 154 779 European Patients. *Radiol Cardiothorac Imaging*,2020;2(5):e200102. doi: 10.1148/ryct.2020200102. PMID: 33778622; PMCID: PMC7977928.
  33. Yuan WF, Zhao XX, Hu FB, Bai C, Tang F. Evaluation of Early Gadolinium Enhancement (EGE) and Cardiac Functional Parameters in Cine-Magnetic Resonance Imaging (MRI) on Artificial Intelligence in Patients with Acute Myocarditis: A Case-Controlled Observational Study. *Med Sci Monit*,2019;25:5493-5500. Doi: 10.12659/MSM.916690. PMID: 31378779; PMCID: PMC6671557.
  34. James L, Menteeer J, Moss LC, Durazo-Arvizu R, Wood JC, Ramos-Platt L, *et al.* Early-Onset Late Gadolinium Enhancement is a Prognostic Factor for Duchenne Cardiomyopathy. *Pediatr Cardiol*,2023;44(2):433-440. Doi: 10.1007/s00246-022-02989-8. Epub 2022 Sep 3. PMID: 36056946.
  35. Weingärtner S, Demirel ÖB, Gama F, Pierce I, Treibel TA, Schulz-Menger J, *et al.* Cardiac phase-resolved late gadolinium enhancement imaging. *Front Cardiovasc Med*,2022;9:917180. Doi: 10.3389/fcvm.2022.917180. PMID: 36247474; PMCID: PMC9557076.
  36. Zhuang X, Xu J, Luo X, Chen C, Ouyang C, Rueckert D, *et al.* Cardiac segmentation on late gadolinium enhancement MRI: A benchmark study from multi-sequence cardiac MR segmentation challenge. *Med Image Anal*,2022;81:102528. doi: 10.1016/j.media.2022.102528. Epub 2022 Jul 9. PMID: 35834896.

37. Theerasuwipakorn N, Chokesuwattanaskul R, Phannajit J, Marsukjai A, Thapanasuta M, Klem I, *et al.* Impact of late gadolinium-enhanced cardiac MRI on arrhythmic and mortality outcomes in nonischemic dilated cardiomyopathy: updated systematic review and meta-analysis. *Sci Rep*,2023;13(1):13775. Doi: 10.1038/s41598-023-41087-4. PMID: 37612359; PMCID: PMC10447440.
38. Paciorek AM, von Schacky CE, Foreman SC, Gassert FG, Gassert FT, Kirschke JS, *et al.* Automated assessment of cardiac pathologies on cardiac MRI using T1-mapping and late gadolinium phase sensitive inversion recovery sequences with deep learning. *BMC Med Imaging*,2024;24(1):43. Doi: 10.1186/s12880-024-01217-4. PMID: 38350900; PMCID: PMC10865672.
39. Saeed M, Van TA, Krug R, Hetts SW, Wilson MW. Cardiac MR imaging: current status and future direction. *Cardiovasc Diagn Ther*,2015;5(4):290-310. Doi: 10.3978/j.issn.2223-3652.2015.06.07. PMID: 26331113; PMCID: PMC4536478.
40. Yilmaz Cankaya B, Kantarci M, Gundogdu F. Evaluation and Comparison of Left Ventricular Functions by Cardiac MRI and 2D Transthoracic Echocardiography. *Eurasian J Med*,2021;53(1):2833. Doi: 10.5152/eurasianjmed.2021.20038. PMID: 33716527; PMCID: PMC7929590.
41. Menchón-Lara RM, Simmross-Wattenberg F, Casaseca-de-la-Higuera P, Martín-Fernández M, Alberola-López C. Reconstruction techniques for cardiac cine MRI. *Insights Imaging*,2019;10(1):100. Doi: 10.1186/s13244-019-0754-2. PMID: 31549235; PMCID: PMC6757088.
42. Sreedhar CM, Ram MS, Alam A, Indrajit IK. Cardiac MRI in Congenital Heart Disease - Our Experience. *Med J Armed Forces India*,2005;61(1):57-62. Doi: 10.1016/S0377-1237(05)80122-4. Epub 2011 Jul 21. PMID: 27407705; PMCID: PMC4923370.