MOLLI T1 Mapping Sequence: the Best Approach for Delayed Enhancement (DE) CMR?

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In the field of cardiac magnetic resonance imaging (CMR), there is a growing interest in tissue characterization and quantification of lesion size, especially myocardial infarct (MI) size. Infarct size is a crucial determinant for patient prognosis and follow-up, and delayed enhancement (DE) gadolinium sequences are established techniques for detecting myocardial infarction and focal myocardial scarring of non-ischemic origin [1, 2].

Nevertheless, since DE-CMR is based on T1-weighted inversion recovery imaging, it intrinsically entails visual interpretation of relative signal intensities in relation to healthy myocardium, and relies on adequate prospective setting of inversion-time during the acquisition. This introduces a user-dependency on the final image quality and achieved contrast-to-noise ratio (CNR) between MI and healthy tissue in the DE-CMR images. This remains true whatever the kernel type used for the acquisition (TrueFISP, FLASH or signal polarity (PSIR, MAGIR)) [3]. PSIR techniques introduced by Kellman et al. [4] undoubtedly alleviate most ambiguities caused by magnitude reconstruction by always warranting a positive contrast of MI lesions related to normal myocardium, but do not ensure an optimized CNR between the two compartments. When relaxation times between lesions and surrounding tissues (blood and myocardium) are similar, lesion detection may remain ambiguous especially in the case of endocardial or papillary lesions.

Synthetic IR reconstructions can provide optimal contrast DE-CMR images

Since MOLLI has the ability to calculate T1 in each pixel of the image, synthetic MAGnitude Inversion-Recovery (MAGIR) or Phase Sensitive Inversion-Recovery (PSIR) images can retrospectively be calculated using the following simple equations:

$$SI(TI)_{PSIR} = 1 - 2x \exp(TI/T1) \quad \text{Eq. 1}$$

and

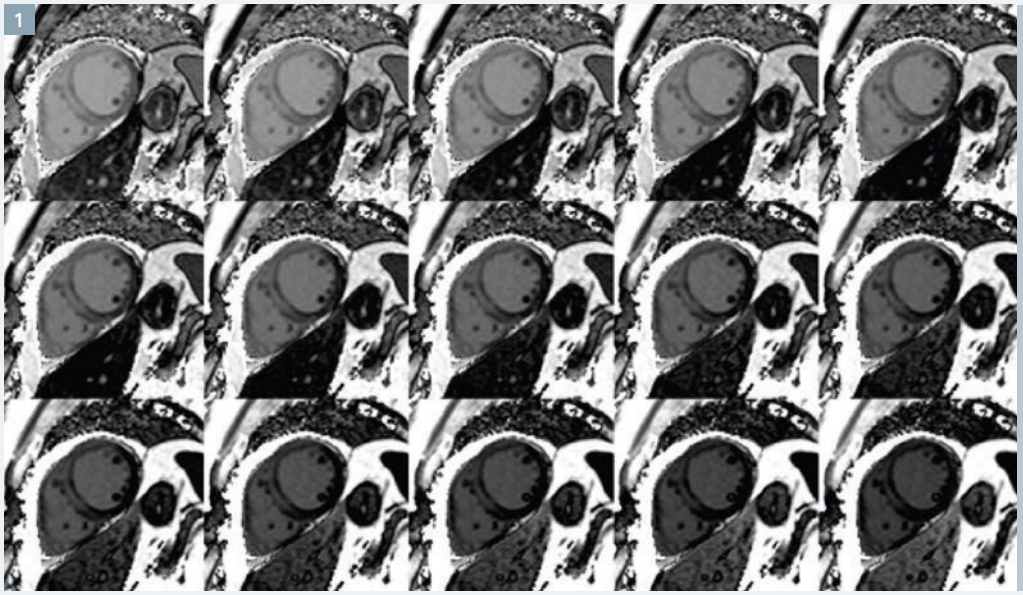
$$SI(TI)_{MagIR} = |SI(TI)_{PSIR}| \quad \text{Eq. 2}$$

Using a small increment in TI, e.g. 10 ms, allows physicians to systematically retrospectively screen a wide range of contrast, for instance between 200 ms and 500 ms, and hence to retrospectively choose the optimal contrast-of-interest between two tissue components best suited to his diagnosis without acquisition time loss, and without requiring additional acquisitions with different TI settings. This approach has first been proposed by Varga-Szemes and co-authors [5].

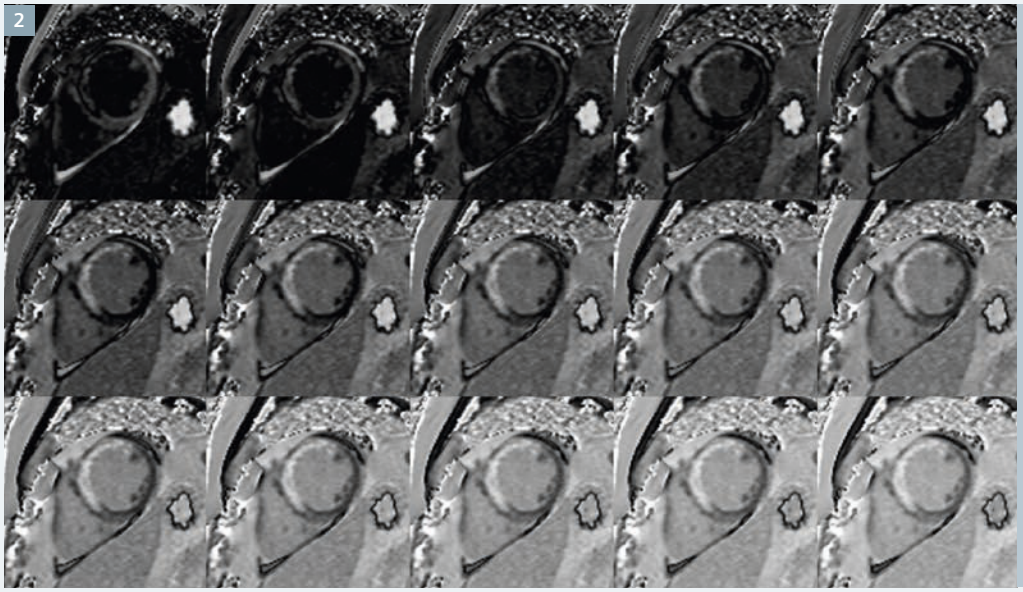
Figures 1 to 3 show an example acquired in a 65-year-old male patient with an inaugural ST elevation myocardial infarction with left anterior descending artery occlusion reperfused H+1h30. CMR was performed 4 days after reperfusion. Native synthetic MAGIR reconstructions (Fig. 1) showed increased signal related to edema in reperfused anteroseptal injured myocardium. Post-gadolinium injection synthetic MAGIR reconstructions performed 10 min after bolus injection (Fig. 2), showed in the same mid slice level the extent of acute anteroseptal necrosis.

Figures 4 to 6 show images acquired in a patient suspected of cardiac amyloidosis with a concentric hypertrophic cardiomyopathy (HCM). Both native and post-contrast injection MAGIR reconstructions allow for intra-myocardial focal lesions in the inferior wall to be identified with confidence, more clearly delineated after injection, with a subtle involvement of the anterior papillary muscle and anterolateral subendocardium.

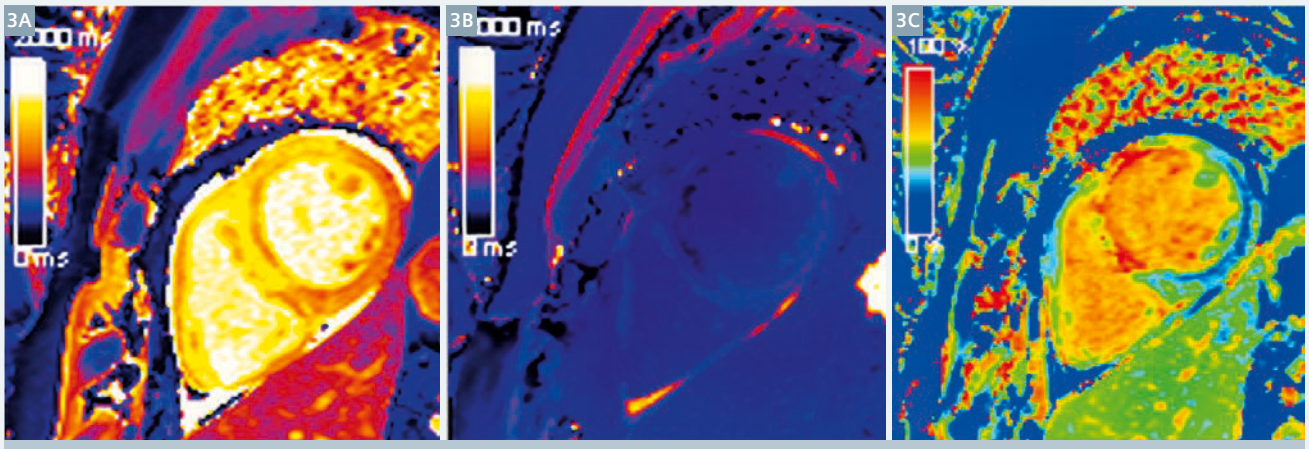
Figure 7 shows a 67-year-old patient with a dilated cardiomyopathy (DCM) that clearly shows after gadolinium injection the extent of a post-ischemic subendocardial scar spread in the anterior wall and extended to anteroseptal and lateral walls, with a partial involvement of the anterior papillary muscle but with an islet of preserved muscle here clearly depicted. Note the existence of a mid-wall fibrosis in the inferoseptal segment raising discussion of the association with a non-ischemic mechanism. All these findings are strengthened by the visual analysis of the contrast



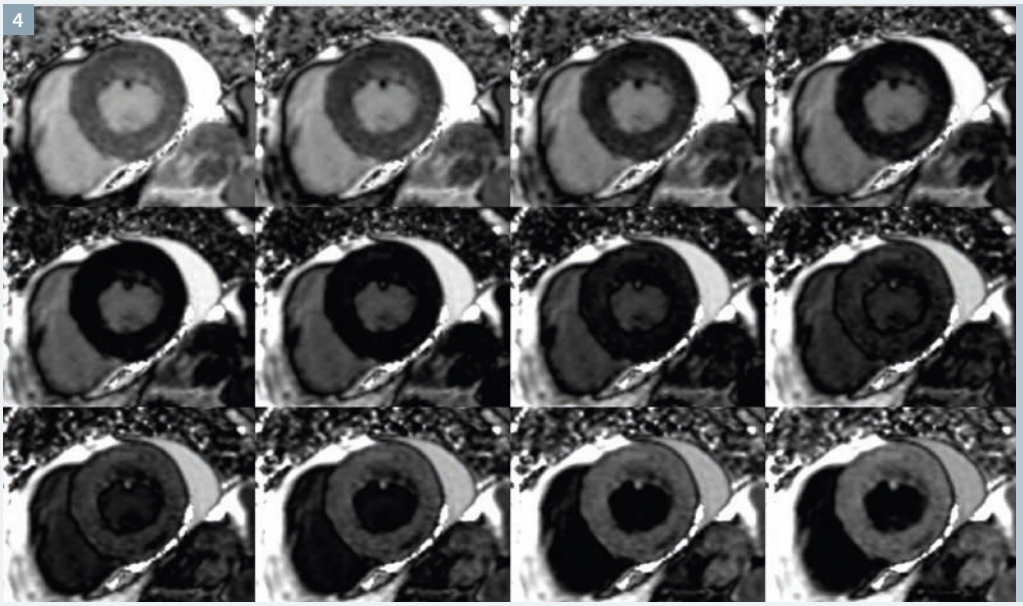
1 15 out of 40 synthetic native MAGIR images in an anterior acute myocardial infarction (AMI) patient. Reconstructed images are TI shifted every 10 ms in a 200 to 500 ms range (1.5T MAGNETOM Aera, *syngo* MR D13).



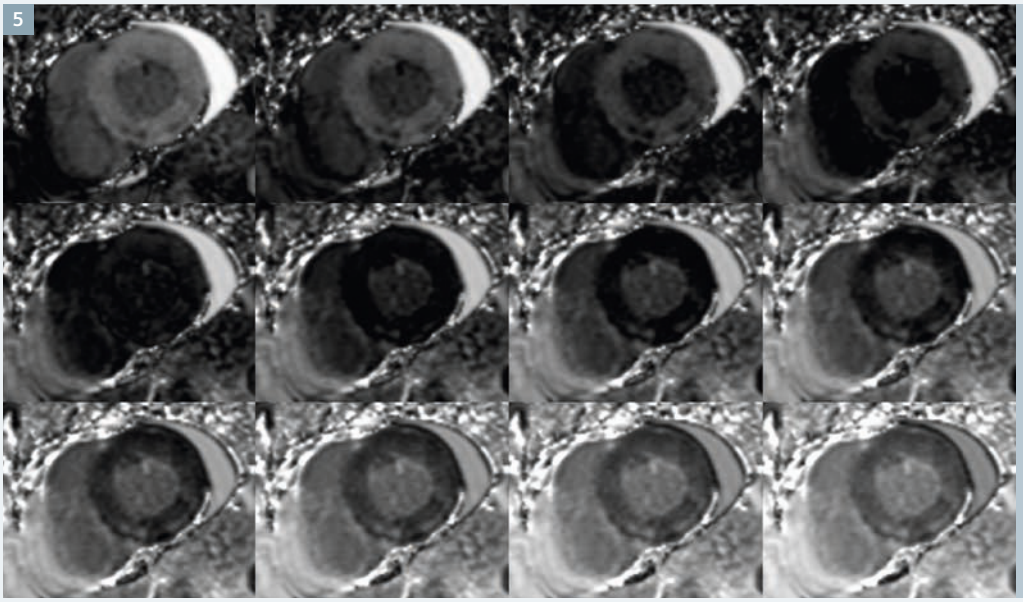
2 15 out of 40 synthetic post-gadolinium injection (0.02 mmol.kg^{-1}) MAGIR images in the same AMI patient. Reconstructed images are TI shifted every 10 ms in a 200 to 500 ms range.



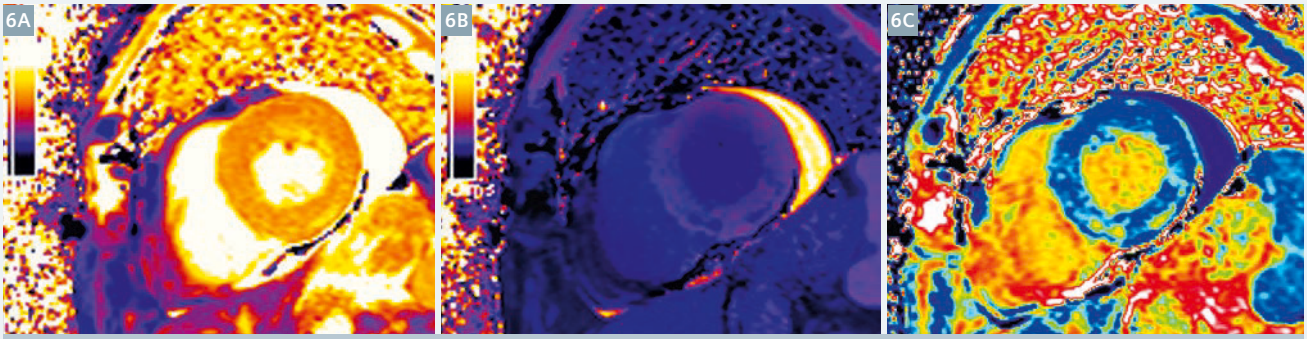
3 Corresponding: **(3A)** Pre-contrast (native) T1 map, **(3B)** post-contrast T1 map and **(3C)** ECV map in the same AMI patient.



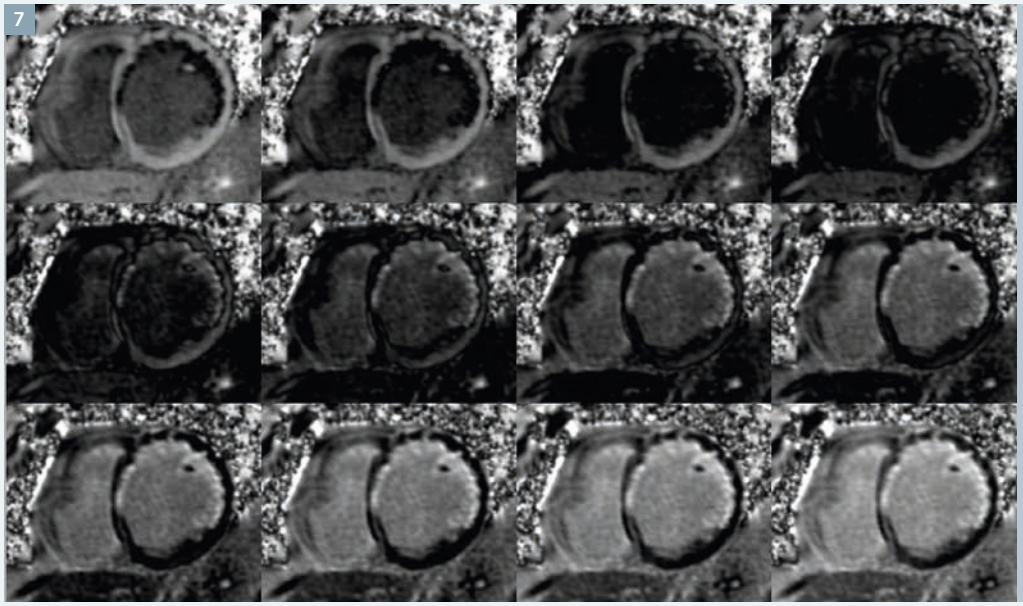
4 12 out of 40 synthetic native MAGIR images in an HCM patient. Reconstructed images are TI shifted every 10 ms in a 200 to 500 ms range (1.5T MAGNETOM Aera, *syngo* MR D13).



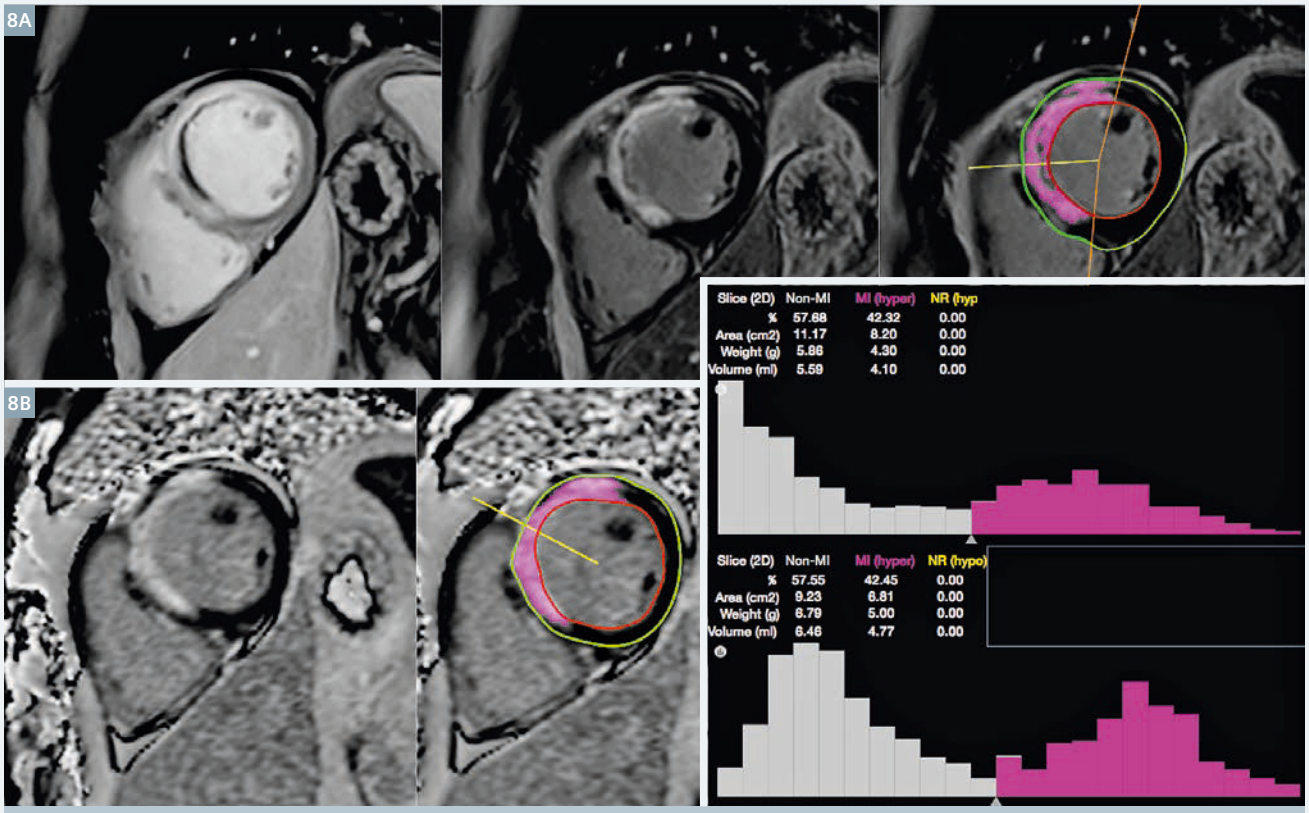
5 12 out of 40 synthetic post-gadolinium injection (0.02 mmol.kg^{-1}) MAGIR images in the same HCM patient. Reconstructed images are TI shifted every 10 ms in a 200 to 500 ms range.



6 Corresponding: **(6A)** Native T1 map, **(6B)** post-contrast T1 map and **(6C)** ECV map in the same patient.



7 12 out of 40 synthetic post-gadolinium injection (0.02 mmol.kg^{-1}) MAGIR images in the same post-ischemic DCM patient. Reconstructed images are TI shifted every 10 ms in a 200 to 500 ms range (3T MAGNETOM Prisma, *syngo* MR E11).



8 Short axis images obtained using 3D IR-GRE: **(8A)** Early gadolinium enhancement and **(8B)** late gadolinium enhancement and corresponding LGE MAGIR and PSIR synthetic images. Calculated histogram of pixel intensity in the myocardium, in the MAGIR optimal contrast as compared to original LGE images. Pink overlay corresponds to the area of delayed enhancement after 10 min post-injection using a Full Width at Half Maximum (FWHM) algorithm (CMRSegTools plugin (CREATIS) with OsiriX, Pixmeo, Geneva).

dynamics across the entire series of TI values that may be determinant in sub-endocardial regions, more difficult to differentiate from the enhanced cavity, especially at 3T, with again an additional information at no additional acquisition time cost.

Taken together, the capability to generate synthetic images and existing T1-mapping and ECV-mapping possibility, the MOLLI acquisitions represent a powerful diagnostic tool in CMR offering a three-in-one advanced tissue characterization technique: Highest capacity to highlight and detect abnormalities while offering quantitative measures of T1 and ECV in absolute units. T1 mapping together with optional synthetic reconstructions therefore provides a unique capacity for objective determination of the severity of disease with integration into clinical routine without extra-acquisition time. It also reinforces robustness of CMR.

Synthetic reconstruction for improved automatic segmentation of MI size

Several histogram-based methods have been proposed for the measurement of DE-CMR infarct size from the simple (manual or semi-automatic thresholding) to the more advanced, including the finite Gaussian mixture (FGM) model where Gaussian likelihood distribution is assumed [6].

These are widely used models in segmentation because they are mathematically simple. Unfortunately, variable CNR, and artifacts limit the performance of histogram-based algorithms that in turn present pitfalls which, under clinical conditions, lead to unreliable results. By eliminating the need for patient-based prospective TI adjustments, synthetic IR images based on T1 mapping offer a satisfactory answer to one of the most significant downsides of conventional DE-CMR acquisition. This technique could potentially offer a unique way to standardize lesion size measurements for multicenter clinical trials.

Of course, other downsides to the automatic segmentation of MI infarct, such as partial volume effects, motivates for high resolution images and thinner slice thickness offered with well optimized 3D IR-GRE sequences, although these come at the cost of the longer acquisition times that most patients are unable to tolerate.

In conclusion, the all-in-one MOLLI including optional synthetic reconstructions reinforces the unique capability of CMR to provide additional information. This in turn may lead to improved diagnostic confidence, increased diagnostic accuracy and improved robustness, alleviating user-dependent adjustments during acquisition, and resulting in the most advanced, and shortest post-gadolinium tissue characterization MR protocol.

References

1 Simonetti OP, Kim RJ, Fieno DS, Hillenbrand HB, Wu E, Bundy JM, Finn JP, Judd RM. An improved MR imaging technique for the visualization of myocardial infarction. Radiology 2001;218:215–223. doi: 10.1148/radiology.218.1.r01ja50215.

2 Kim RJ, Fieno DS, Parrish TB, Harris K, Chen E-L, Simonetti O, Bundy J, Finn JP, Klocke FJ, Judd RM. Relationship of MRI Delayed Contrast Enhancement to Irreversible Injury, Infarct Age, and Contractile Function. Circulation 1999;100:1992–2002. doi: 10.1161/01.CIR.100.19.1992.

3 Viallon M, Jacquier A, Rotaru C, Delattre BMA, Mewton N, Vincent F, Croisille P. Head-to-head comparison of eight late gadolinium-enhanced cardiac MR (LGE CMR) sequences at 1.5 tesla: from bench to bedside. J Magn Reson Imaging 2011;34:1374–1387. doi: 10.1002/jmri.22783.

4 Kellman P, Arai AE, McVeigh ER, Aletras AH. Phase-sensitive inversion recovery for detecting myocardial infarction using gadolinium-delayed hyperenhancement. Magn Reson Med 2002;47:372–383. doi: 10.1002/mrm.10051.

5 Varga-Szemes A, van der Geest RJ, Spottiswoode BS, Muscogiuri G, De Cecco CN, Suranyi P, Rehwald WG, Schoepf JU. Quantification of myocardial late gadolinium enhancement using synthetic inversion recovery imaging. Journal of Cardiovascular Magnetic Resonance 2015;17(Suppl 1):O8.

6 Kim HW, Farzaneh-Far A, Kim RJ. Cardiovascular Magnetic Resonance in Patients with Myocardial Infarction. Journal of the American College of Cardiology 2010;55. doi:10.1016/j.jacc.2009.06.059.

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