Cardiovascular Magnetic Resonance. Late Gadolinium Enhancement Imaging: A Technologist's Guide

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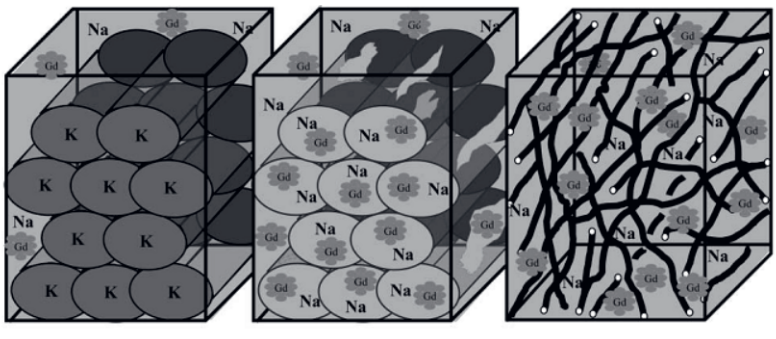
Introduction

There is little doubt that one of the many great strengths of cardiac MRI (CMR) is its ability to assess tissue characterization within the myocardium. A key event in the evolution of CMR was first reported by M Saeed et al. in 1989. They described the technique of using T1-weighted MR images after the administration of an intravenous contrast injection to differentiate between healthy and infarcted myocardium [1]. Over 30 years later, this practice is now well established and provides vital prognostic and pathological information to guide patient management. The technique is now commonly referred to as late gadolinium enhancement (LGE) and is firmly established in nearly all CMR protocols.

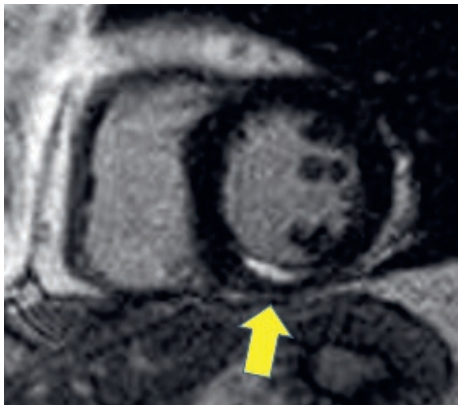
Physiology of scar imaging with gadolinium

Following an intravenous injection of a gadolinium chelate to the patient, the gadolinium will circulate into the myocardium, where it will occupy the extracellular space. In healthy myocardium, it will not cross the intact cell membrane of the myocyte, and as the myocytes are densely packed together there is little extracellular space for them to linger, so over time the gadolinium will simply wash out [2]. In areas of necrotic or fibrotic myocardium, the myocyte cell membrane will rupture and the extracellular space will increase. The gadolinium will accumulate into what was previously intracellular space due to the deterioration of the myocyte membrane. In an area of chronic pathology, the myocytes are broken down and replaced with collagenous scar. This increases the volume of extracellular space available to the gadolinium molecules, which then become ensnared within the collagen matrix [3], see Figure 1 [4].

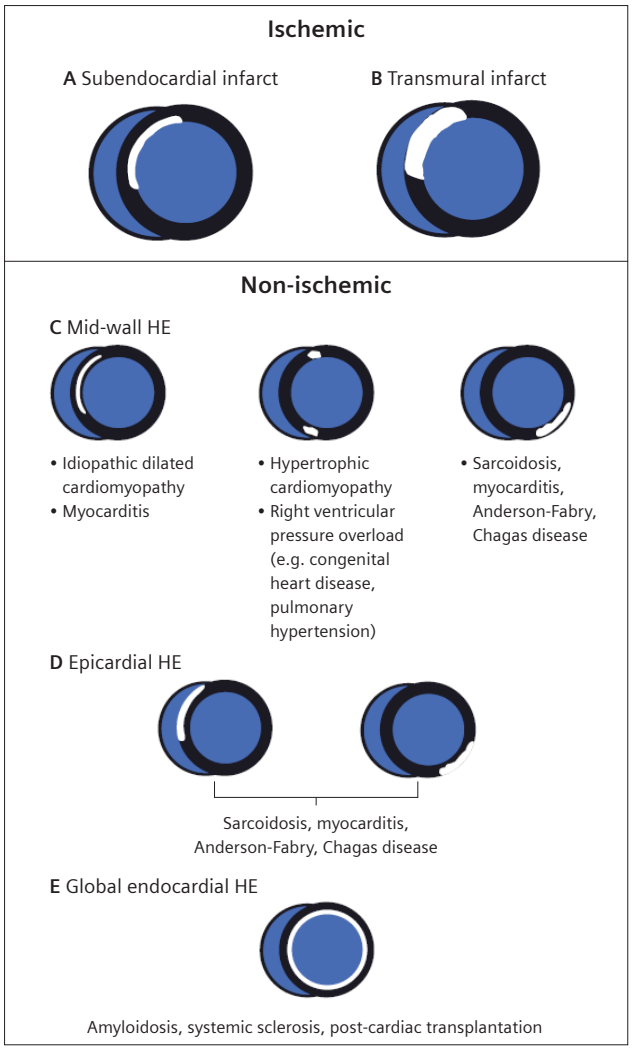
By using gadolinium to shorten the T1 relaxation time of any voxels in which the gadolinium is present, myocardial injury such as scar and fibrosis will be identified by a bright, hyper-enhanced signal intensity in the area where the contrast has accumulated (Fig. 2) [5].



1 How the myocytes deteriorate, and the relationship with the gadolinium molecules at a cellular level. *Reproduced with permission from [4].*



2 Small focal area of sub-endocardial scar (yellow arrow) in the inferior myocardium of the left ventricle, seen on a mid short-axis LGE image.



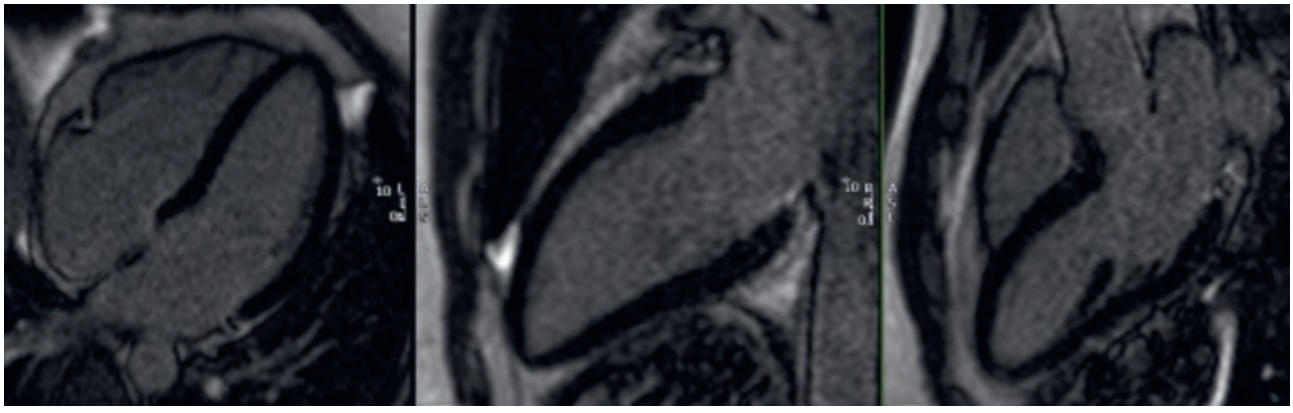
3 Mahrholdt et al. [6] illustrate the different locations and patterns of myocardial scar, and the associated cardiac diseases. *Reproduced with permission from [6].*

Clinical application

The LGE technique is used to characterize various cardiac pathologies. By demonstrating the location of the scar/fibrosis, it is possible to distinguish ischemic from non-ischemic cardiac disease. In the early stages of ischemic infarction, scar will develop in the inner band of myocardium adjacent to the blood pool (subendocardial myocardium), and then over time spread to the outer wall of the myocardium (epicardium). Once this has occurred, the scar will now be present across the whole thickness of the myocardium (trans-mural). By visualizing the various patterns of fibrosis and scar in the myocardium, it is possible to classify many different non-ischemic cardiomyopathies. These different patterns of scar were very nicely illustrated by Mahrholdt et al. in 2005 [6] (Fig. 3).

Imaging technique

As users of technology from Siemens Healthineers, we have many options available to us when acquiring LGE images. In general practice, a 2D segmented inversion recovery (IR) gradient echo (GRE) or balanced steady state free precession (bSSFP) pulse sequence is used (Fig. 4). The LGE images should be acquired in all three long-axis positions, and a stack of short-axis images to include both ventricles. Two right ventricular long-axis imaging positions may also be required, depending on the imaging protocol. When positioning and acquiring your LGE images, it is of paramount importance that these images are prescribed in the same position as the cinematography and tissue characterization sequences. This will allow the reporting clinicians to effectively compare all the different sequences at the same position in the heart. A uniform slice thickness, slice gap, and field of view applied to all sequences will aid this process and provide consistent imaging throughout the CMR study.



4 LGE imaging using a 2D segmented PSIR sequence prescribed in 4C, 2C, and 3C long-axis orientations.

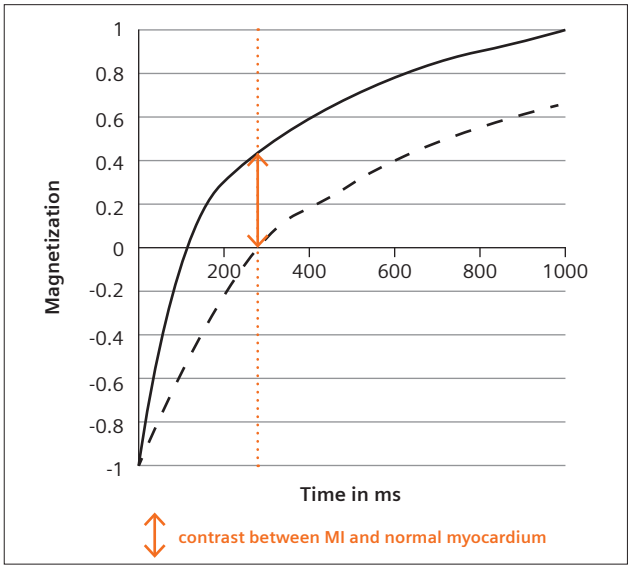
Data acquisition for our LGE sequences should be set to late diastole to ensure that we are imaging when the myocardium is fully relaxed and motionless. Clicking on the Capture Cycle icon in the physio card will set our TR and acquisition window to the appropriate position in the heartbeat (Fig. 5). Always ensure that data collection does not occur on top of the second R wave or within the next heartbeat, as this will cause a cardiac motion ghosting artifact on the images.

Inversion time

Setting the correct inversion time is a critical component of acquiring diagnostic and high-quality images. As already mentioned, the purpose of this technique is to identify areas of high signal (scar) within the myocardium. For this to be easily visualized, the healthy myocardium should be black, with a low signal. This technique is known as nulling the myocardium. After the administration of gadolinium, the magnetization of the healthy myocardium will fall below the level of 0. Over time, as the gadolinium washes out of the healthy myocardium, the magnetization will begin to increase. The perfect time to image the myocardium is when the magnetization is at 0 and therefore nulling the signal from healthy myocardium. Figure 6 [7] shows that when the healthy myocardium is nulled, the necrotic tissue will have a higher magnetization value, as the gadolinium present within it has shortened the T1 relaxation time. Necrotic tissue will therefore have a bright signal compared to the dark, healthy myocardium.

The TI scout sequence should be used approximately 7–10 minutes after administering the gadolinium. This valuable sequence will provide several images with different TI times, usually at intervals of between 20 and 80 milliseconds (Fig. 7). Scroll through the stack of images and simply choose the image in which the myocardium appears as black as the lung fields. Note the TI time displayed on this image and type it into the physio card for your LGE sequences.

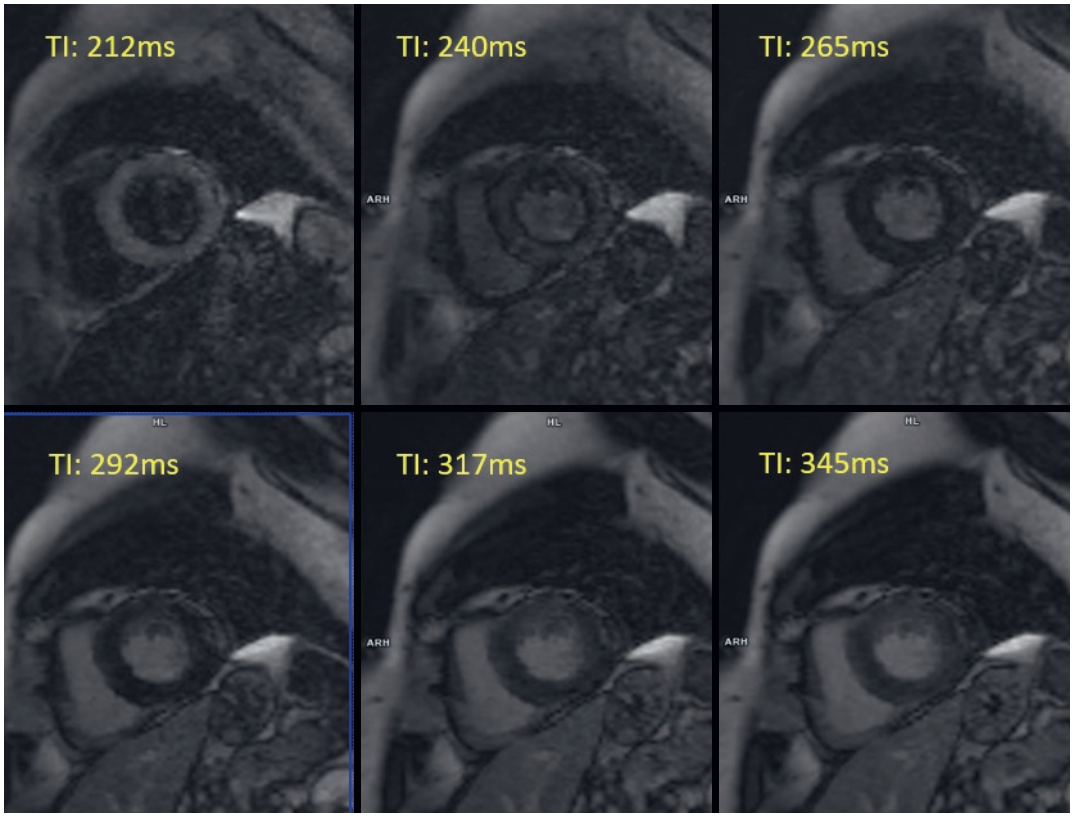
The TI scout is a valuable educational tool when learning how to null the myocardium and for differentiating between images that have an inversion time which is too low or too high. By studying the images, you will learn to understand the subtle differences of when an LGE image has an incorrect TI and how to correct it. An image which demonstrates a low TI will display a tramline nulling pattern. The myocardium will have a high signal, but at the endocardium and epicardium borders you will clearly see two dark lines circumferentially (Fig. 8). When a TI is set too high, the whole myocardium will have a homogenic high-signal appearance (Fig. 9).



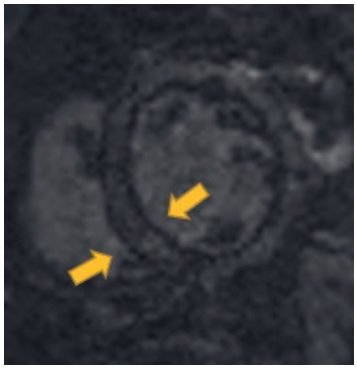
6 The dotted line represents the T1 relaxation time of healthy myocardium, whereas the solid line represents necrotic tissue.

5 Screenshot of the physio signal window on a 1.5T MAGNETOM Sola. The green column in the heartbeat shows the optimal data acquisition time for an LGE sequence.

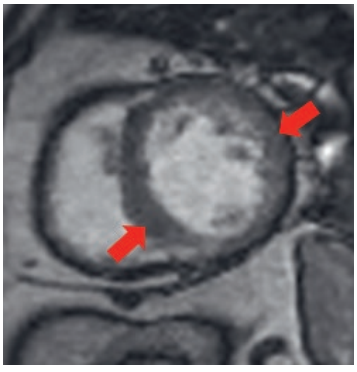
It is essential that technologists understand several significant factors which influence the TI value of healthy myocardium. The contrast dose is the first consideration. In the 2020 update of its standardized cardiovascular magnetic resonance imaging (CMR) protocols [8], the Society for Cardiovascular Magnetic Resonance (SCMR) recommends that a gadolinium contrast dose of between 0.1 and 0.2 mmol/kg (body weight) is given to the patient. In practice, a single dose of 0.1 mmol/kg is often used, but this remains at the discretion of the local clinicians and protocols. If a standard dose of 0.1 mmol/kg is administered, LGE imaging will commence approximately 10 minutes after the injection. If imaging is started too early, the blood pool and healthy myocardium will both contain gadolinium, resulting in similarly high signal intensities. This will reduce the contrast between the subendocardial border of the myocardium and blood-pool interface, and therefore limit the ability to diagnose scar tissue in this region. Imaging too early will also make it impossible to appropriately null the healthy myocardium.



7 TI scout images showing ascending TI measurements.



8 SA LGE image showing tramline nulling pattern (orange arrows) as the TI is too low.



9 SA LGE image showing homogenic high signal in the myocardium as the TI is too high.

The age and physical nature of the patient can sometimes influence the wash-out time of the gadolinium contrast. In my experience, tall, thin, and younger adults will wash out contrast sooner than others. It is therefore prudent to perform a TI scout slightly earlier than you would normally, to avoid missing the optimal imaging window. I would also recommend starting LGE imaging slightly earlier in patients who have undergone a vasodilated stress perfusion examination, as this technique will also increase gadolinium wash-out.

Tips and tricks for successful LGE imaging

Cross-cut and phase-swap imaging

As described earlier in this article, scar/fibrosis can be described in a variety of sizes and locations within the myocardium. If a large amount of scar/fibrosis is present, it will be easy to detect and diagnose. However, in many cases there are subtle focal areas of scar/fibrosis which may be less identifiable. It is therefore important for technologists to be suspicious of all small areas of high signal within a properly nulled myocardium. It is our duty to help determine if this finding is a pathology or an artifact. There are two techniques which will assist us in verifying if an area of high signal is true scar/fibrosis or an imaging artifact.

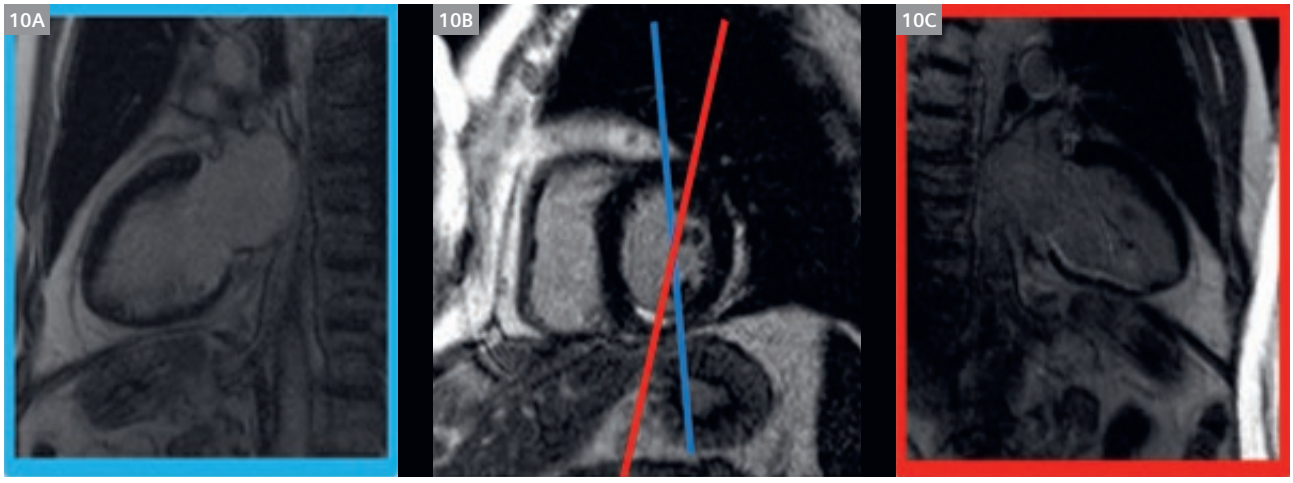
The first technique is known as cross-cutting and should be used when detecting a small focal area of high signal, even if you are confident that it is scar/fibrosis. Simply position your LGE sequence perpendicular to the area of high signal so that the new image is orthogonal to the original image. You can see from the example below (Fig. 10) that this technique will effectively demonstrate the area of high signal and provide detailed information on the total size and location of the scars/fibrosis. Figure 10 also shows that when a cross-cut slice is positioned from a short-axis image, it will provide additional information which is not necessarily identifiable on the original three long-axis images.

The phase-swap technique is required when there are areas of high signal across the heart which have the appearance of a ghosting artifact. By changing the phase-encoding direction when acquiring the image for a second time, any artifacts will move away from the area of interest. If an area of high signal does not change, you have proven that it is not an artifact and can be considered a true physiological finding. The example below (Fig. 11) shows how a ghosting artifact from a large pleural effusion has ghosted across the heart. By changing the phase-encoding direction, the artifact moved away from the heart. It is paramount that no artifacts are present on the images as they can result in a false-negative or false-positive diagnosis.

Fast imaging to reduce motion artifacts

Like all CMR sequences, the 2D segmented LGE sequence will be negatively affected by motion artifacts. However, Siemens Healthineers provides us with imaging solutions which can deliver good-quality diagnostic images in the most challenging of patients.

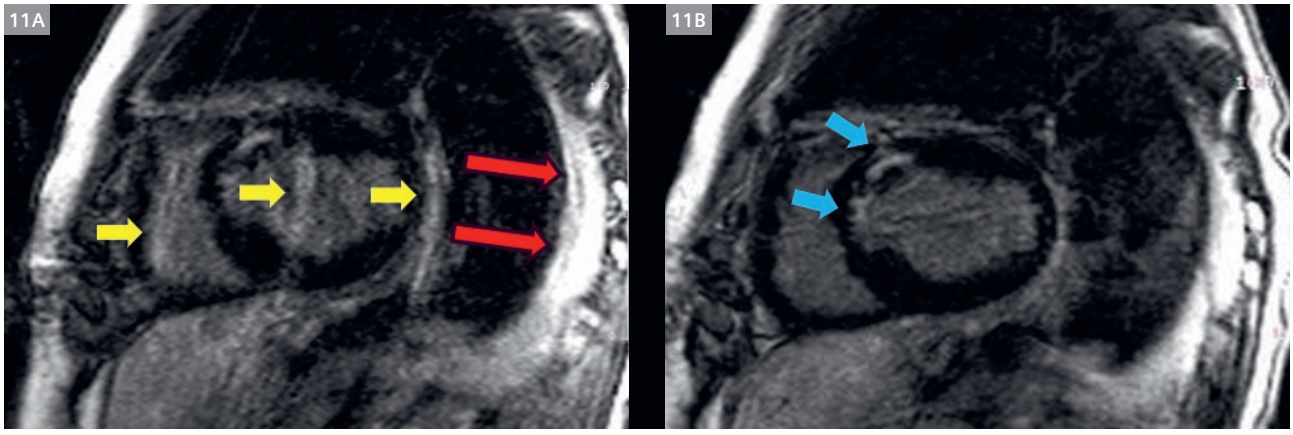
The single-shot phase-sensitive inversion recovery (PSIR) sequences have been part of our protocols for many years. They provide a quick and easy solution for imaging patients who cannot hold their breath, are arrhythmogenic, or both. Clinically, I always run this sequence right after the TI scout as a free-breathing SA stack to provide



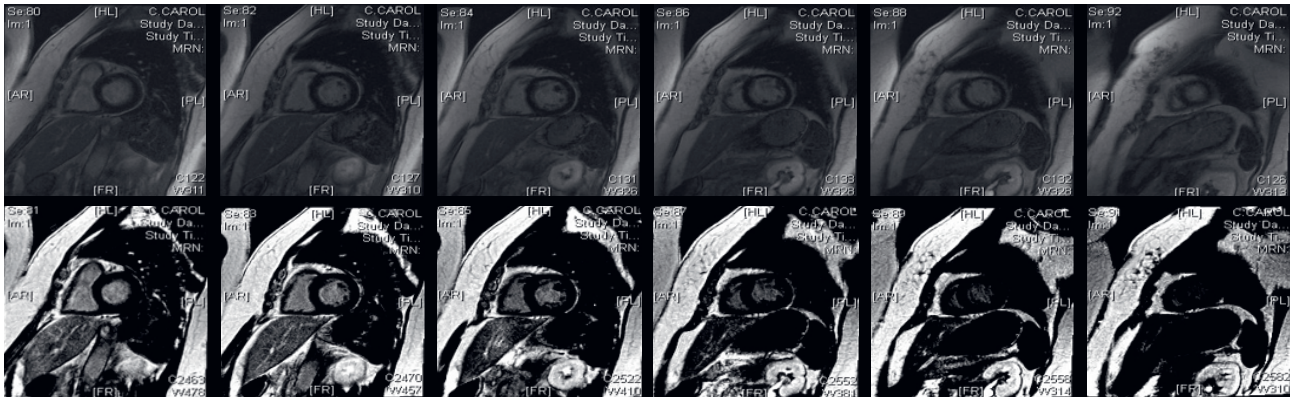
10 **(10A)** LGE short-axis image showing a small focal area of high signal in the inferior wall. The red line demonstrates a cross-cut slice position perpendicularly through the area of high signal. **(10B)** The resulting cross-cut image demonstrates a sub endocardial area of scar along the inferior wall. **(10C)** This image shows how the scar could have been missed by an ill-positioned 2C slice, which is demonstrated by the blue line on image (10A).

immediate diagnostic LGE information of the whole myocardium in under 30 seconds. We then apply the 2D segmented LGE sequence in the three LA slice positions. Using the single-shot SA stack immediately gives you the safety net of having acquired the important LGE data just in case the patient aborts the scan prematurely. The single-shot images provide good temporal and spatial resolution, which means some clinicians are happy to report their findings on these images alone. However, in some patients where there may be subtle areas of scar/fibrosis, or the image quality is average, using a full SA stack of 2D segmented PSIR images will be required. Figure 12 shows an example of a single-shot SA stack image set.

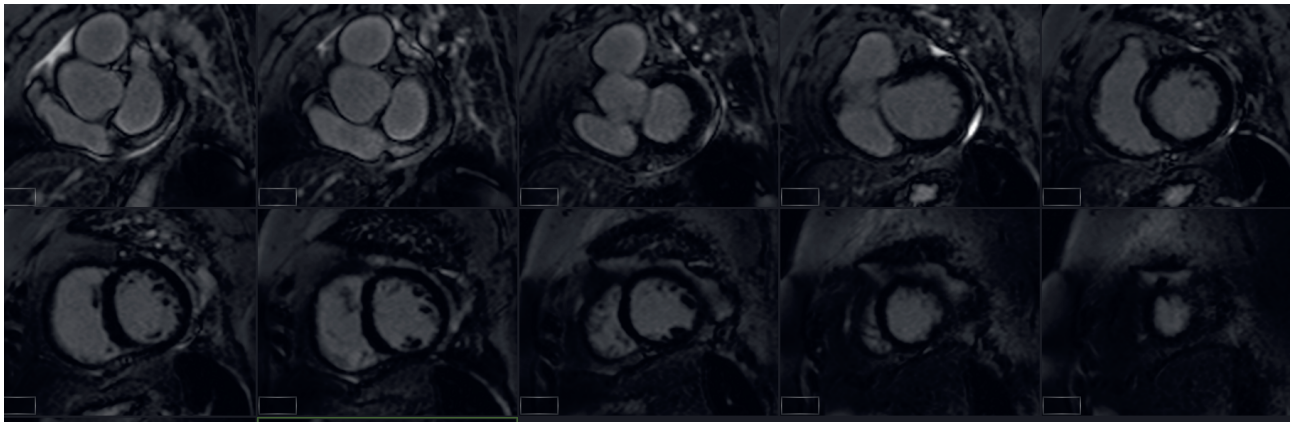
The latest, state-of-the-art LGE sequence to be released by Siemens Healthineers is called PSIR HeartFreeze. It benefits from a newly developed motion compensation algorithm which provides high-resolution LGE imaging in a free-breathing acquisition. This sequence has proven to be a game changer for LGE imaging, with clinicians across the world now using it as part of their standard protocol. A study by Captur et al. [9] found greater reporting concordance and confidence when using the motion-correction free-breathing PSIR–SSFP sequence compared to a segmented PSIR–FLASH breath-hold sequence. The new sequence was also shown to reduce overall scanning time, which has paved the way for the development of a rapid CMR protocol. For those departments that still prefer to use a 2D segmented sequence for their patients, PSIR HeartFreeze offers a reliable alternative in acquiring good-quality images in patients who cannot hold their breath or are arrhythmogenic. Figure 13 displays LGE images that are good quality despite the data being acquired from a patient in atrial fibrillation.



11 Image **(11A)** shows a large pleural effusion (red arrows) which is causing ghosting artifacts (yellow arrows) across an SA LGE image. Image **(11B)**: After changing the phase-encoding direction and repeating the image, the ghosting artifact has been removed. Importantly, the two areas of focal scar in the septal myocardium have remained unchanged, therefore verifying that they are not artifact but rather a true pathology.



12 A selection of images taken for a short-axis stack using a single-shot PSIR LGE sequence. Top row: Phase images. Bottom row: Magnitude images.



13 A short-axis stack acquired using a single-shot PSIR HeartFreeze LGE sequence in a patient with atrial fibrillation. These images are the phase reconstruction using a motion-corrected algorithm.

Conclusion

In this article I have endeavored to describe the unique imaging method of LGE, which is an essential element in the CMR service. I have illustrated several imaging intricacies and offered advice to technologists on how to acquire good-quality images. As MRI technology evolves, so will our imaging practices. Siemens Healthineers continues to lead the way in developing and advancing its MRI hardware and software technologies. As well as benefitting our patients, this also provides robust, reproducible, and user-friendly imaging strategies and solutions for all CMR technologists and clinicians to employ and enjoy.

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