

Advances in Magnetic Resonance Imaging of the Myocardial Area at Risk and Salvage

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Cardiac Magnetic Resonance: Role in Infarct Characterization

Cardiac magnetic resonance (CMR) imaging in survivors of acute ST-segment-elevation myocardial infarction (STEMI) provides accurate and precise measurements of left ventricular dimensions, and infarct pathologies are uniquely characterized. Acute coronary artery occlusion initiates a wavefront phenomenon of ischemia¹ commencing from the endocardial layer and propagating radially toward the epicardium, and typically, myocardial infarction will supervene unless coronary reperfusion is achieved in a timely manner. The myocardial area at risk is the jeopardized perfusion territory of the culprit artery.

See Article by Nordlund et al

Ischemia results in an increase in myocardial water content manifesting as myocardial edema, and the local changes in T1 and T2 relaxation times (milliseconds) can be revealed by CMR.² Myocardial salvage is calculated by subtracting the infarct size on contrast-enhanced CMR from the myocardial area at risk, revealed by T1- or T2-weighted CMR, and predicts the likelihood of functional recovery.² On the contrary, edema imaging has limitations because the area at risk diminishes in size from ≈ 5 days post reperfusion,^{3,4} and T2 relaxation times within the ischemic zone vary as infarct pathologies evolve.^{5,6}

Imaging Myocardial Edema

Several CMR methods are now available for imaging myocardial edema⁷; the most established of which is the T2-weighted short tau inversion recovery (T2-STIR) black blood technique. This method has the advantage of being generically available across all major vendors. However, image quality may be limited when using T2-STIR CMR because of low contrast-to-noise ratio between normal and abnormal myocardium and a propensity for subendocardial bright rim artifacts because of static blood and surface coil issues.^{8,9} In recent clinical trials involving optimized core laboratory analyses, T2-STIR

has not been of diagnostic value in at least one quarter of all scans.^{10,11} In our opinion, this limitation is unacceptable. New alternative methods include T1 mapping¹² and T2 mapping,¹³ which like T2-STIR require additional breath-hold acquisitions specifically for the purpose of imaging edema. Contrast-enhanced cine steady-state free precession (CE-SSFP)¹⁴ depicts edematous myocardium as a region of higher T2:T1 signal than normal myocardium.¹⁵ This new method has recently gained traction as an alternative approach for assessing the area at risk after being validated against single photon emission computed tomography¹⁴ and T2-STIR.¹⁶

Relationship Between the Culprit Artery, the Myocardial Area at Risk, and Infarct Size and Location

Knowledge of the distribution and size of the coronary artery perfusion territories is clinically relevant. For example, identification of the culprit artery and estimation of salvageable myocardium subtended by that artery could promote novel applications, such as (1) the development of automated software for area-at-risk and infarct analyses, (2) be used as a surrogate outcome measure in therapeutic clinical trials, (3) provides tools to aid clinicians in practice, for example, validation of novel ECG algorithms.

In this issue of *Circulation: Cardiovascular Imaging*, Nordlund et al¹⁷ compared CE-SSFP against T2 STIR for the assessment of the ischemic area at risk and myocardial salvage in 215 survivors of an index acute STEMI enrolled into 2 clinical trials: Efficacy of Endovascular Catheter Cooling Combined With Cold Saline for the Treatment of Acute Myocardial Infarction (CHILL-MI; NCT01389261) and Multicenter, randomized, double-blind, placebo controlled study to assess safety and efficacy of TRO40303 for reduction of reperfusion injury in STEMI patients undergoing primary PCI (MITOCARE; NCT1374321). The in-plane resolution of both methods was $\approx 1.5 \text{ mm} \times 1.5 \text{ mm} \times 8 \text{ mm}$. The temporal resolution of CE-SSFP was 20 to 30 frames per second. Nordlund et al¹⁷ also set out to compare their results with previous publications on identifying the culprit artery using single photon emission computed tomography.^{18,19} The CMR image analyses were performed in a core laboratory using software designed by the same group in the University of Lund, Sweden. The CMR findings from assignment of the culprit artery territory were compared with the reference findings from the invasive coronary angiogram, taking into account the Rentrop collateral grade and infarct assessment using late gadolinium enhancement imaging with CMR. The study builds on previous work done by Ortiz-Pérez et al²⁰ who used contrast-enhanced CMR to map infarct distribution to identify the culprit artery in 93 STEMI survivors.

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The first main finding was that, as compared with CE-SSFP, a higher number of T2-STIR scans were not of diagnostic value (86 [40%] versus 13 [6%]). Of those scans that were interpretable, the area at risk (% left ventricular mass) was similar. CE-SSFP had a higher rate of agreement with angiography in assigning the culprit artery than did T2-STIR (97% versus 89%). The area at risk revealed by CE-SSFP was greater than infarct size in all of the subjects. The second main finding was that the CE-SSFP may reflect the true perfusion territory of the reperfused culprit artery. The third finding was that area at risk revealed by CE-SSFP and T2-STIR (using the subset of scans that were of diagnostic value) was similar to the findings in previous studies of culprit artery distribution using myocardial perfusion scintigraphy.^{18,19}

The results provide evidence that CE-SSFP is an emerging alternative option for edema imaging. It is intriguing that a noninvasive multimodality CMR scan can be used to identify the location of the culprit artery, its perfusion territory, and the amount of residual myocardium amenable to salvage.

Some potential limitations of the CE-SSFP method include the fact that diagnostic accuracy will likely be reduced in nonreperfused STEMI because the intravascular contrast agent would not be expected to perfuse the infarct territory. Because the study involved patients with a first STEMI, in whom coronary collateral connections may be minimal, the diagnostic accuracy of CE-SSFP merits further assessment in a less selected and more heterogeneous population of STEMI patients.

Advances in Imaging the Myocardial Area at Risk

There is a divergence of opinion in the cardiovascular imaging community^{5-7,21,22} on whether the hyperintense area revealed by T2-weighted imaging in patients with recent STEMI reflects the ischemic area at risk or instead may simply reflect infarct size. We recognize the theoretical limitations of edema imaging, especially with T2-STIR.⁴⁻⁷ The new applications with T1 mapping, T2 mapping, and CE-SSFP represent important advances, which strengthen the case for imaging the myocardial area at risk and salvage with CMR. Early post-MI the extent of edema (% LV mass) seems reasonably stable between days 3 to 10,^{3,4} but in general evolves dynamically within the first 2 - 3 days,^{4,6} and falls progressively after the first week.^{3,4}

Utility of CE-SSFP Imaging

In the study by Nordlund et al,¹⁷ out of 215 CMR scans acquired using technology from different vendors, only 11 CE-SSFP sets were not of diagnostic quality. The scans from 2 other patients were of diagnostic quality, but the area at risk was not apparent. The CE-SSFP approach seems reasonably robust. It is particularly attractive because the data can be acquired from the standard cine scans that are acquired for left ventricular mass and function, without the need for additional breath-hold edema imaging acquisitions. Therefore, the overall duration of the CMR scan would be shorter using CE-SSFP¹⁷ as compared with when additional scans are acquired for edema imaging. Further validation of the accuracy and performance of CE-SSFP¹⁷ against T2 parametric mapping¹³ and T1 mapping techniques¹² is warranted.

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Disclosures

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