Radiology

Steps and Leaps on the Path toward Simpler and Faster Cardiac MRI Scanning

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Edema is an invariable feature of acute tissue injury. In the heart, it occurs in the wake of ischemic, inflammatory, microbial, or toxic injury. Its presence can indicate acute cellular injury but also ongoing inflammation as part of the host's defense or as part of the recuperation of tissue integrity. In the absence of irreversible injury with significant cellular damage (necrosis), edema typically indicates that the injury is reversible.

The verification of myocardial edema and its regional distribution pattern may provide crucial information on the cause, stage, and severity of such an injury. This is of particular importance in patients with symptoms suggesting acute myocardial injury (angina and shortness of breath) of unknown causes because these symptoms are not specific to the cause and often neither to its severity. The presence of myocardial edema and, just as important, its intramyocardial distribution, typically provides strong clues for differentiating coronary (ischemic) from nonischemic causes, such as stress-induced Takotsubo cardiomyopathy or myocarditis (1). Edema of a coronary territory, typically associated with at least some, mostly subendocardial, necrosis as visualized with late gadolinium enhancement, is typical for ischemic injury, whereas inflammatory or other causes typically lead to a more diffuse pattern of intramural distribution that is not predominantly subendocardial. As an important piece of clinical information, the presence of edema in the absence of irreversible injury indicates viable myocardium with the potential to fully recover.

In patients with multivessel coronary artery disease presenting with a recent clinical event, knowledge about the coronary territory affected by the recent injury may inform decisions on coronary interventional planning. In patients after late-presenting myocardial infarction, large areas of edema without necrosis or scarring can indicate salvageable myocardium, although associated inflammation surrounding any infarction must be taken into account. In patients with myocarditis and arrythmia, edema can indicate that the arrhythmia may be reversible, and a decision regarding the implantation of a defibrillator can be informed. In cardiomyopathies caused by diseases such as Fabry disease, amyloidosis, or sarcoidosis, knowledge about the presence of myocardial edema helps guide medical treatment. Myocardial T2 has also shown an independent prognostic value in myocardial injury caused by myocarditis, infarction, cardiomyopathies, or in transplant rejection (2).

For decades, T2-weighted cardiac MRI, typically using a triple-inversion recovery spin-echo sequence, has dominated myocardial edema imaging, but because of the relatively low signal-to-noise ratio and motion artifacts (3), T2 mapping is increasingly used instead of signal intensity in spin-echo images (4). Although myocardial T1 has received much attention and is an excellent marker for tissue injury, it is undisputed that T2 maps are more specific to myocardial water content and thus edema.

Cardiac MRI myocardial mapping, however, has been limited by its moderate spatial resolution, motion artifacts, and the variability of quantitative results between scanners and sequences (5). Furthermore, incomplete coverage raised concerns about its sensitivity to help identify regional edema. In this context, the technique suggested in this issue of *Radiology* (6) represents a significant step toward more robust and user-independent edema imaging of the heart.

Bustin et al (6) achieved remarkable results using an accelerated free-breathing high-spatial-resolution three-dimensional (3D) whole-heart T2 mapping sequence based on a T2-prepared steady-state free precession approach. The sequence has several advantageous features. Besides providing full 3D coverage, it is extremely efficient in data acquisition (using navigators) and, because of fivefold undersampling, comes with a relatively short acquisition time of about 7 minutes. Motion correction is accounted for by a so-called mutual information similarity algorithm. The actual T2 map is eventually generated with the use of patient-specific dictionary matching.

After verifying the technical accuracy of the sequence in phantom experiments and demonstrating in vivo reproducibility in eight healthy participants, Bustin and colleagues performed a clinical evaluation in 25 patients with clinical evidence for acute myocarditis. The findings

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Conflicts of interest are listed at the end of this article.

See also the article by Bustin et al in this issue.

indicated robustness in a clinical setting and a higher incidence of abnormalities in resulting images, suggesting a high sensitivity.

Strengths of the study include validation in phantoms and the verification of reproducibility of results. The proposed method may indeed represent a significant improvement in imaging acute myocardial disease. As Bustin and colleagues confirm, full coverage of the heart comes with a higher sensitivity for helping detect regional edema, and the free-breathing protocol simplifies scanning for both technologists and patients when compared with standard sequences with repeated breath holds.

Cardiac MRI as an extremely informative diagnostic tool has thus been hampered by complex scanning protocols, a plethora of tissue contrast options, and therefore a need for specific expertise and experience. In times of limited resources in health care, expensive scanner times must be used efficiently, and therefore, standard protocols must be robust, simple, and time efficient. From this perspective, the proposed technique is a step in the right direction. It reduces complexity by being 3D with full coverage (reducing the need for individual section planning), by being inherently native (no contrast material needed), and by working in a free-breathing mode.

As part of a comprehensive cardiac MRI scan that also includes morphologic findings and function, however, a T2 mapping sequence must be combined with cine imaging, T1 maps, and late gadolinium enhancement imaging. As long as such protocols continue to require multiple protocol sequences, they may need to compete with a novel class of MRI sequences that can be called a simultaneous multiparametric acquisition and reconstruction technique, or SMART, cardiac MRI. This includes MRI fingerprinting (7), MRI multitasking (8), the free-running framework (9), and low-rank patch-based undersampled reconstruction (10). These sequences can be performed during free breathing and some of them without electrocardiographic triggering. They can provide T1 maps, T2 maps, as well as cine and other images. The images are calculated from random κ-space data with the help of machine learning–driven reconstruction algorithms. This approach will likely result in markedly simplified MRI scanning and will allow for pursuing the vision of a "one click" examination with short scanning times and no need for repeated, breath-hold scanning. This is particularly relevant to cardiovascular applications that usually require more individual planning, a wider variety of sequences per scan, and a stronger susceptibility for motion artifacts. Some of these techniques are still under development, but it is abundantly clear that we are witnessing a significant leap forward. Experience with free-breathing 3D mapping as presented in this article will inform the development and implementation of SMART techniques and their architecture.

In patients suspected of having acute myocardial disease, T2 mapping is complementary with high-sensitivity troponin in not only identifying the presence, but also the actual cause of acute myocardial injury. The unique nature of MRI edema imaging is increasingly well understood in state-of-the-art clinical environments, where myocardial edema imaging is a useful diagnostic tool. The proposed 3D free-breathing sequence can help simplify this and therefore is a useful step that helps make cardiac MRI in such patients more time and cost efficient.

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