MRI of left ventricular function

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Cardiac magnetic resonance imaging (CMR) is widely recognized as the most accurate noninvasive imaging modality for the assessment of left ventricular (LV) function. By use of state-of-the-art magnetic resonance imaging (MRI) scanners, electrocardiography (ECG)–gated cine images depicting LV function with high contrast and excellent spatial and temporal resolution are readily acquired in breath-holds of 5 to 10 heartbeats. For patients in whom breath-holding and ECG gating are difficult, real-time cine imaging without ECG gating and breath-holding can be performed. LV function can be qualitatively assessed from cine images, or alternatively, parameters such as LV volumes, ejection fraction, and mass may be quantified via computer-based analysis software. In addition, techniques such as myocardial tagging and newer variants can be used to qualitatively or quantitatively assess regional intramyocardial strain, twist, and torsion. Many of the CMR methods have undergone clinical evaluation in the settings of high-dose dobutamine stress testing and determination of myocardial viability. These methods are also very accurate for prognosis in coronary heart disease patients and may be quite useful for the detection of contractile dyssynchrony. When used together with other CMR techniques such as first-pass perfusion imaging or late gadolinium enhancement, CMR of LV function provides a wealth of information in a single imaging study. (J Nucl Cardiol 2007;14:729–44.)

INTRODUCTION

The accurate assessment of global and regional left ventricular (LV) function by imaging is clinically important in many types of heart disease. In coronary artery disease (CAD), ejection fraction (EF) and end-systolic volume are important predictors of survival and are used to manage therapy. Imaging global and regional LV function during dobutamine infusion can reveal underlying coronary artery stenoses and identify viable myocardium. In addition, imaging to determine the synchrony of LV contraction may be more accurate than QRS morphology for predicting the response of heart failure patients to cardiac resynchronization therapy (CRT).

Echocardiography is the most widely used modality for noninvasive imaging of LV function because of its efficacy, relatively low cost, portability, and widespread availability. Limitations of echocardiography include the need for adequate acoustic windows and, for 2-dimensional (2D) imaging, operator dependence and the use of geometric assumptions in computing volumes. Gated single photon emission computed tomography (SPECT) is also used for noninvasive imaging of global and regional LV function, although it has relatively low spatial and temporal resolution. Although echocardiography and SPECT are the most popular modalities for imaging the heart, cardiac magnetic resonance imaging (CMR) is the most accurate modality for the evaluation of LV function in normal subjects and patients. As such, CMR is often used as the gold standard for evaluating other modalities.

In this article CMR methods for imaging LV function and their application to CAD are reviewed. Conventional electrocardiography (ECG)–gated cine CMR, real-time cine CMR, and tissue-tracking methods such as myocardial tagging and newer variants are covered. Application of these methods to myocardial infarction (MI), dobutamine stress testing, and LV dyssynchrony is discussed. The article concludes with a discussion of the integration of LV function imaging with other CMR techniques such as late gadolinium enhancement (LGE).

METHODS

Breath-Hold Segmented ECG-Gated Cine MRI

As shown in Figure 1, ECG-gated multiphase, or cine, CMR acquires 1 segment (a group of individual lines) of image raw data per heartbeat for each cardiac phase. Over the course of multiple heartbeats, multiple segments comprising a complete set of raw data for all cardiac phases are acquired. This common method of imaging, which is usually performed during a short period of breath-holding, typically has an in-plane spatial resolution of approximately 1.5 × 2 mm², since
thickness of 5 to 10 mm, and temporal resolution of 30 to 50 milliseconds per frame. Example images are shown in Figure 2. The acquisition of data during suspended respiration eliminates motion artifact due to breathing. By acquiring a segment of raw data, as opposed to a single line of raw data, in each heartbeat, a complete image data set can be acquired in a fraction of the time required for nonsegmented techniques. By use of an array of radiofrequency receiver coils and parallel imaging acquisition and reconstruction methods with a conservative acceleration factor of $2^{12}$, typical scan times of 6 to 7 heartbeats per slice are now routine.

Multislice imaging is typically performed as a sequence of breath-hold acquisitions and generally includes both short-axis and long-axis views. Unlike echocardiography, well-defined arbitrary scan planes can be prescribed so that multiple short-axis planes and specific long-axis planes such as 2-, 3-, and 4-chamber views are readily and reproducibly acquired. In general, blood appears bright and myocardium appears gray or dark gray in these images. However, the specific appearance of blood, myocardium, and blood flow depends on whether spoiled gradient echo or steady-state free precession (SSFP) is used for signal generation within the segmented data acquisition structure.

**Spoiled Gradient Echo and SSFP**

Before 1999, breath-hold cine CMR was generally performed via spoiled gradient echo imaging for signal generation. As a result of inflow into the imaging slice of blood that has not previously experienced radiofrequency excitation, blood typically appears bright whereas myocardium typically appears gray with this method.

Whereas image quality was considered quite good for spoiled gradient echo cine CMR, SSFP imaging of the heart was subsequently developed and yields even better signal-to-noise and contrast-to-noise ratios. By use of this approach, blood—which has a long spin-spin relaxation time—appears bright regardless of the degree of inflow. Also, by use of an excitation flip angle of 50° to 70°, myocardium appears quite dark, resulting in superb myocardium-blood contrast (Figures 2 and 3A) and, subsequently, excellent delineation of the endocardial border even when blood flow is very slow. SSFP was not practical before about 2000 because it is prone to dark-band artifacts resulting from magnetic field inhomogeneity when the repetition time is longer than approximately 4 to 5 milliseconds. However, with the availability of high-performance gradient systems starting in the late 1990s, state-of-the-art MRI systems can now routinely achieve a repetition time of less than 4 to 5 milliseconds and, consequently, acquire artifact-free SSFP images of the heart. Example images comparing ECG-gated segmented acquisitions via spoiled gradient echo and SSFP for signal generation are shown in Figure 3.

In addition to different image contrast, SSFP and spoiled gradient echo also differ in sensitivity to turbulent flow. Specifically, because SSFP generally uses shorter echo times and is to some degree inherently motion-compensated, this technique is less sensitive to motion-induced signal loss compared with spoiled gradient echo. This effect leads to a more uniform appearance of blood in cine images, which improves the appearance of most images. However, this effect also decreases sensitivity to turbulent flow. If sensitivity to turbulence is desired, such as in suspected valvular disease, then spoiled gradient echo images should be acquired.

**Real-Time Imaging**

For patients who have difficulty holding their breath or when ECG gating is unreliable either for technical reasons or because of arrhythmias, CMR offers the ability to perform