Specialty Area: Cardiac MRI: Function, Perfusion & Viability

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Highlights:

- The fundamental basis for estimating cardiac perfusion with dynamic contrast-enhanced MRI is signal changes that occur during first passage of contrast agent; normally perfused tissues appear relatively bright, whereas hypoperfused tissues appear relatively dark
- Image acquisition must be fast enough to track the bolus of contrast agent passing through multiple planes of the heart; the most commonly used pulse sequence is saturation-recovery TurboFLASH
- Dynamic contrast-enhanced images can be analyzed qualitatively, semi-quantitatively, or quantitatively
- Major confounders include "dark rim" artifacts, nonlinear relationship between signal and [Gd], and cardiac and respiratory motion

Title: Technical Foundations: Physics of Perfusion Imaging

Target audience: Basic science and clinical imagers involved with cardiovascular MRI

Objectives: Upon completion of this educational presentation, the participants should be able to:

- Understand the fundamental basis for assessment of myocardial perfusion with dynamic contrast-enhanced MRI
- Understand the basics of image acquisition and analysis
- Understand the pitfalls of cardiac perfusion MRI and how to address them, to the extent that it is possible
- Appreciate the benefits of k-t acceleration methods to increase the spatio-temporal resolution and/or spatial coverage

Purpose/Introduction: First-pass cardiac perfusion MRI (1-4) has been an active area of investigation for over 2 decades. Recent clinical trials have shown that cardiac perfusion MRI is as accurate as SPECT for coronary artery disease (CAD) detection (5-7). Cardiac perfusion MRI features higher spatial resolution than SPECT; this advantage may be beneficial for detection of subendocardial perfusion defects. This presentation will cover the basics of cardiac perfusion MRI, including image acquisition and image analysis. For more details on key factors that are critical for successful cardiac perfusion MRI, please see (8, 9).

Methods: (Image Acquisition) First-pass perfusion MRI is the one of most challenging cardiovascular MRI techniques; it needs to be performed rapidly to acquire multiple (3-4) planes of the heart with high temporal resolution (~150 ms), and repeated for about 1 min to characterize the bolus kinetics (see Figure 1). Consequently, the intrinsic SNR is relatively low; the dynamic range of signal over time is wide, which makes it challenging to optimize the pulse sequence parameters. The most commonly used pulse sequence is saturation-recovery (SR) TurboFLASH. Other possible readouts include segmented EPI (10, 11) and b-SSFP (12-14), but they are more susceptible to image artifacts than TurboFLASH (13).

Figure 1. A typical protocol using SR based T1-weighted imaging. This schematic shows 3 cardiac plane acquisitions per heart beat.

(Signal-to-[Gd] Conversion) For quantitative evaluation of myocardial perfusion, one must convert the signal to concentration of contrast agent [Gd]. When choosing a SR delay (TD), the user must consider multiple factors, which include: myocardial enhancement (longer TD, higher SNR), arterial input function (shorter TD, less clipping of peak signal), spatial coverage (longer TD, less time to acquire multiple planes). Figure 2 shows examples that compares different results with varying TD. With shorter TD, the images suffer from lower SNR but avoids signal clipping for the AIF (i.e., accurate). With longer TD, the images have higher SNR but suffers from signal clipping for AIF (i.e., underestimation). This conundrum can be avoid by acquiring the AIF acquisition with short TD and myocardial wall acquisitions with long TD (15-17), or with a dual-bolus approach (18).

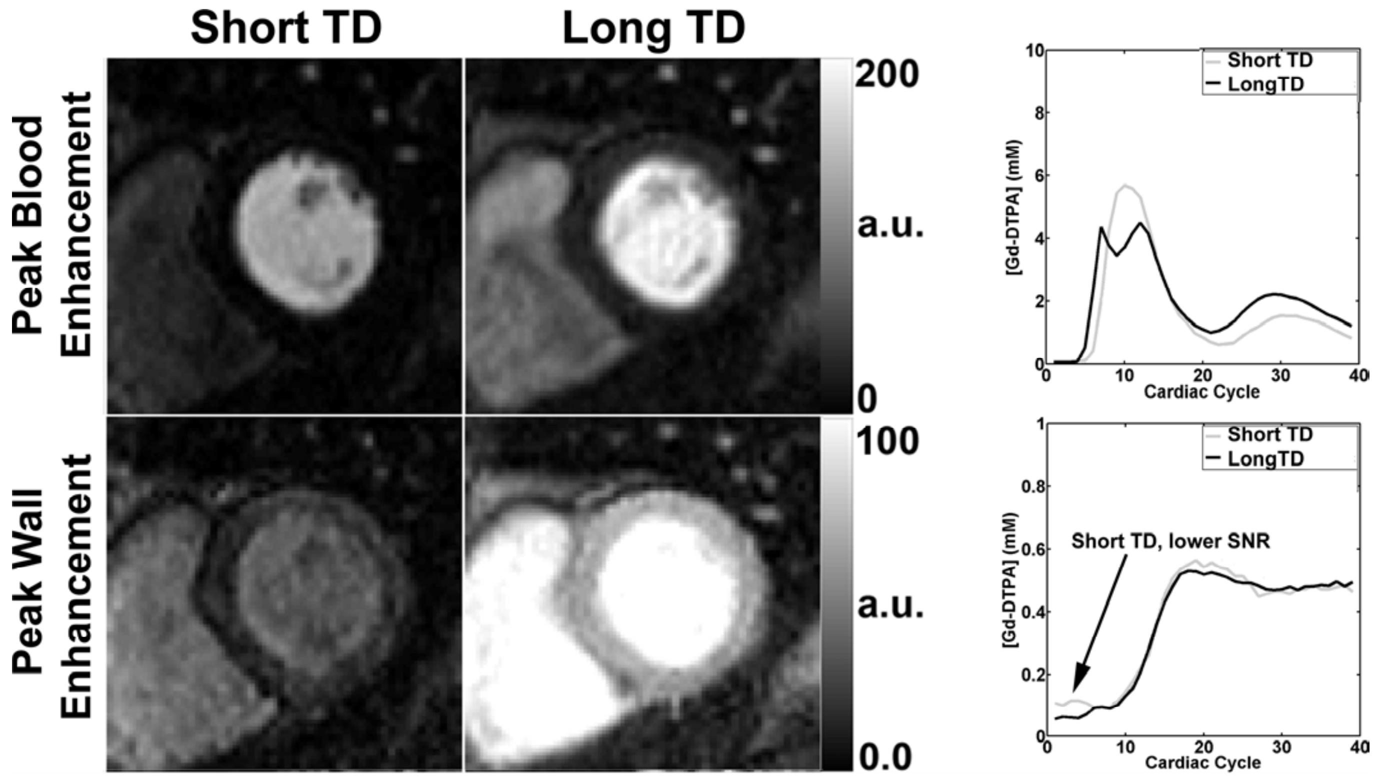

Figure 2. Images at peak blood and wall enhancement acquired with short and long TD, as well as their resulting [Gd]-time curves. These examples display the challenge in balancing between accuracy of AIF and SNR of myocardial wall.

(Perfusion Estimation) The method of choice to estimate myocardial perfusion will depend largely on the experience level of the imaging center. Qualitative evaluation is the most common in clinical practice. Semi-quantitative evaluation methods (myocardial perfusion reserve index) are also available (19, 20). Quantitative evaluation methods can improve accuracy and help detect multi-vessel disease (21, 22), but require extensive expertise and experience to produce reliable results.

Results: Figure 3 shows a perfusion image with high resolution (2 mm x 2 mm x 8 mm) and temporal resolution (45 ms) that was used to diagnose CAD (23). The perfusion defects in the mid-anterior wall correspond to reversible ischemia (negative LGE) caused by severe in-stent stenosis in the first large diagonal branch, whereas defects in the mid-septal wall correspond to chronic MI (positive LGE) caused by total occlusion in the left anterior descending branch. These MRI images are consistent with X-ray angiography as shown. Note that this rapid perfusion image acquisition with radial k-space undersampling and constrained reconstruction (24, 25) suppresses dark rim artifacts, owing to the high spatio-temporal resolution (26).

Discussion: Cardiac perfusion MRI is a clinically useful method for CAD detection. Technically, cardiac perfusion MRI is one of the most challenging cardiovascular MRI methods; it needs to be performed rapidly to acquire multiple (3-4) planes of the heart with high temporal resolution (~150 ms), and repeated for about 1 min to characterize the bolus kinetics. Recent advances in acceleration methods provide a means to extend spatial coverage and/or increase spatio-temporal resolution. These methods include non-Cartesian acquisitions (27), dynamic parallel imaging (28), and k-t acceleration methods (29-31). These promising methods, while encouraging, will need to be tested rigorously in clinical settings to ensure they yield high accuracy for CAD detection. Finally, for clinical translation, more robust and easy to use analysis methods are needed to achieve reliable estimates of myocardial perfusion.

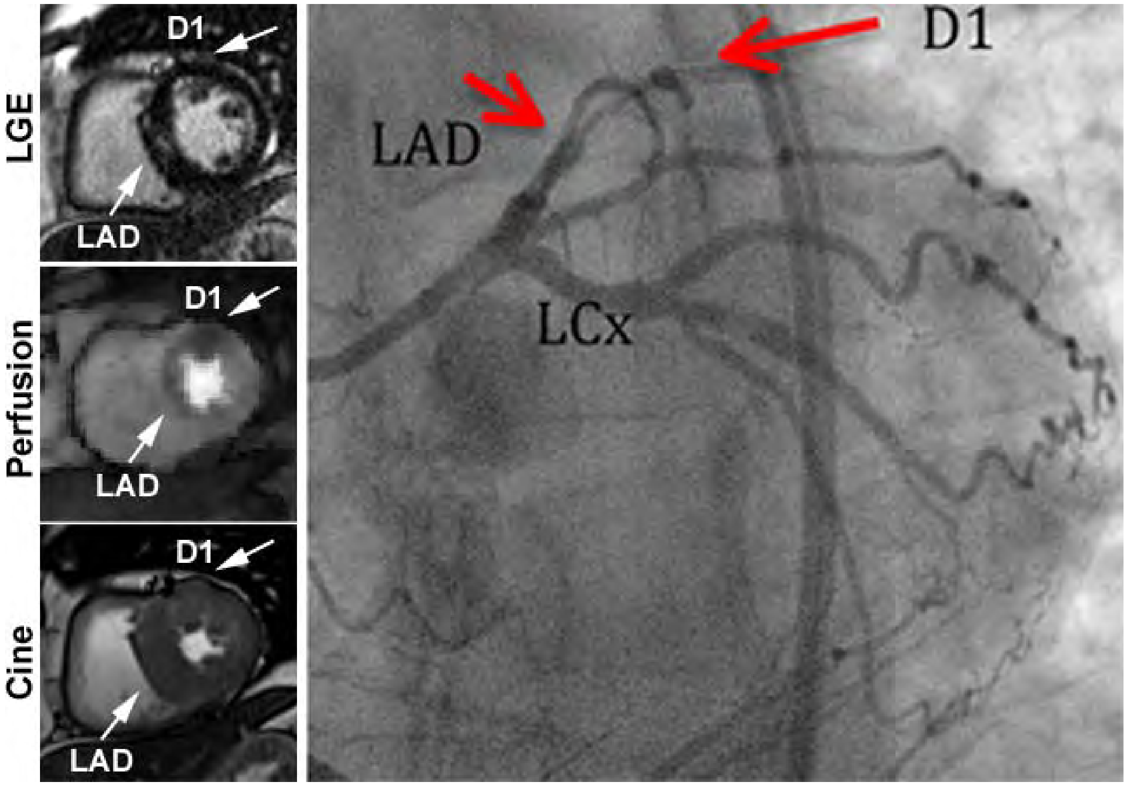

Figure 3. Agreement between X-ray angiography (right) and comprehensive cardiac MRI: LGE (left, top), stress perfusion (left, middle), cine (left, bottom). The perfusion defects in the mid-anterior wall correspond to reversible ischemia (negative LGE) caused by severe in-stent stenosis in the first large diagonal (D1, red arrow) branch, whereas defects in the mid-septal wall correspond to chronic MI (positive LGE) caused by total occlusion in the left anterior descending (LAD, red arrow) branch.

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