Cardiac Perfusion

Technical Foundations: How is it done?

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Introduction: The evaluation of myocardial perfusion is performed with the goal of detecting any flow-limiting lesions in the coronary arteries, and also to assess the functional status of the myocardial microcirculation. The vast majority of such studies are performed today by dynamic imaging during the first pass of a contrast bolus, and using standard extracellular contrast agents, with a fraction of contrast crossing the capillary barrier during the first pass of the contrast bolus. The presentation will focus on methods for contrast-enhanced studies of myocardial perfusion.

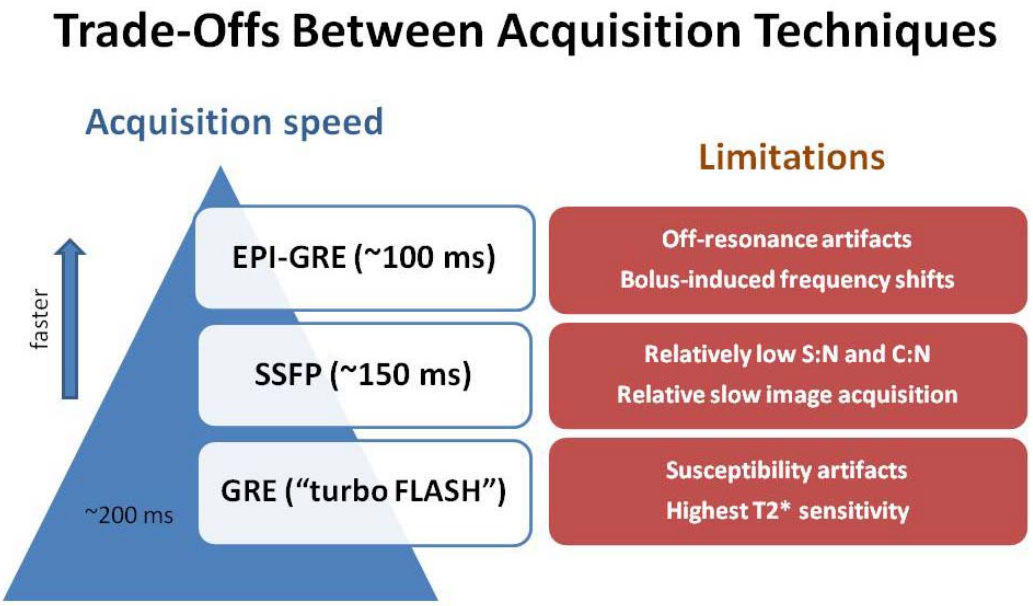

Figure 1: *Cardiac perfusion imaging can be based on different image acquisition techniques, such as fast gradient-recalled-echo (GRE), gradient echo imaging with steady-state free precession (SSFP), or a hybrid of echo-planar imaging (EPI) and GRE, where k-space segments are read-out in echo-planar mode. The listed limitations of these techniques also imply that at least EPI-GRE, and SSFP-based perfusion techniques are best suited for ≤1.5 Tesla.*

Perfusion Image Acquisition: The pulse sequence techniques that are used for contrast-enhanced myocardial perfusion imaging have two key ingredients. They are the contrast enhancement characteristic and the image read-out. With most pulse sequence techniques for first pass imaging these two aspects are dealt with, by first applying a magnetization preparation, followed by image read-out. The magnetization preparation can be a saturation preparation, which by definition nulls the bulk longitudinal, and transverse magnetization components, or an inversion preparation. The image read-out follows the magnetization preparation, with a possible delay that controls the T1-weighting of measured signal. For the image read-out the primary concerns are the speed with which the image is

read-out, the signal-to-noise ratio, and a lack of motion, or susceptibility artifacts. Figure 1 summarizes some of the considerations for image-read-out. Although motion artifacts can be reduced already by virtue of fast image read-out, the read-out of the signal can even with a very fast image read-out be corrupted by motion if the pulse sequence uses a long echo time. Therefore, one of the fastest image acquisition methods, the single shot echo-planar technique, is seldom used for myocardial perfusion imaging without a segmented acquisition (i.e. as EPI-GRE hybrid). Also the transit of a contrast bolus through the ventricular cavities can cause susceptibility artifacts, and a shift of the proton resonance frequency[1] in adjacent regions, which suggests that techniques sensitive to magnetic susceptibility effects and/or frequency shifts should be avoided. Figure 2 summarizes the sequence techniques that are most commonly used for myocardial perfusion imaging.

In this presentation we will discuss some important technical challenges for myocardial perfusion imaging:

1) Acceleration of image acquisition by sparse sampling in the spatial or temporal domains: how it works and typical trade-offs.[2,3]
2) Use of surface coils, and the confounding effects of the spatial variation of the coil sensitivity profile.[4]
3) Imperfections of magnetization preparation due to B1 inhomogeneities, its effects on assessment of perfusion, and the detection of perfusion defects, and corrective measures.[5]
4) How to obtain an arterial input function that can be used for the quantitative evaluation of myocardial perfusion.[6,7]
5) How to avoid artifacts mimicking subendocardial perfusion defects ("dark rim artifacts"). [8]

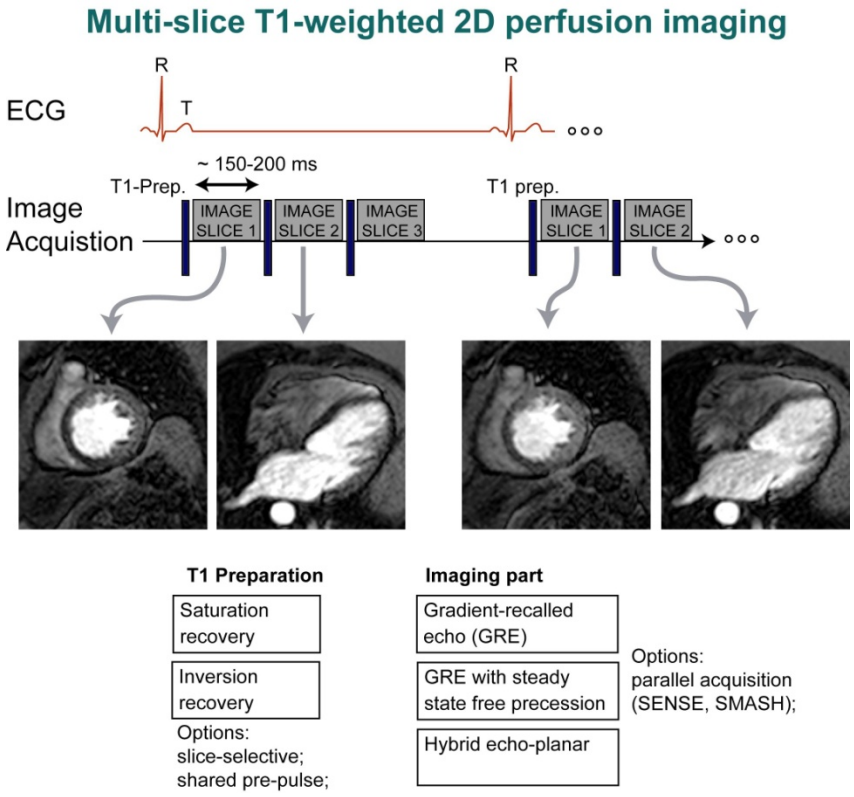

Figure 2: *General scheme for rapid, ECG-gated, 2D, multi-slice, dynamic, T1-weighted imaging during the first pass of a contrast bolus. Images are acquired through-out the cardiac cycle to maximize the slice*

coverage, and image acquisition is repeated during every R-to-R interval. Lower temporal resolution for evaluation of contrast enhancement should be avoided in particular during stress studies. Images can be obtained for a combination of short and long-axis slices, with minimal interference artifacts if a saturation-preparation is used for T1-weighting, as illustrated by the middle row of images in this figure. For similar contrast-enhancement characteristics, the magnetization preparation should be repeated for each slice, rather than using a single magnetization preparation that is shared by all images acquired during an R-to-R interval.

Acceleration Techniques for Perfusion Imaging: Imaging acceleration is required for covering more than 2-3 slices per R-to-R interval. Spatial acceleration techniques such as SENSE[9] and GRAPPA[10] are routinely used for perfusion imaging with acceleration factors on the order of x2. These involve acceleration of each image acquisition by under-sampling in the phase-encoding direction, and taking advantage of the spatial sensitivity information from use of an array of multiple receiver coils. Temporal correlations in dynamic studies can also be explored for temporal under-sampling. Techniques such as UNFOLD[11], k-t BLAST[12], k-t GRAPPA[13], or TSENSE[14] fall into this category, and have been used to accelerate cardiac perfusion studies.
Techniques such as SENSE and k-t BLAST still aim at reconstructing images from data that meet the Nyquist sampling requirements. More recently, compressed sensing techniques have been developed to allow pseudo-random sub-Nyquist sampling, assuming that the image data can be put in a sparse representation. If appropriate criteria are met, it is then still possible to recover the image without significant artifacts.

Alternatives to Cartesian k-Space Sampling: Radial and spiral k-space trajectories can help to speed up image acquisitions in cardiac perfusion imaging. Radial undersampling sampling has been combined with temporal interleaving in a technique called HYPR (highly constrained back-projection).[15] Conjugate-gradient (CG) reconstruction is used to enforce fidelity of the image with the under-sampled data. This CG-HYPR technique allows undersampling factors on the order of 5-10, and has higher contrast-to-noise ratios than e.g. SENSE- or GRAPPA-based acquisitions with similar acceleration factors. [16]

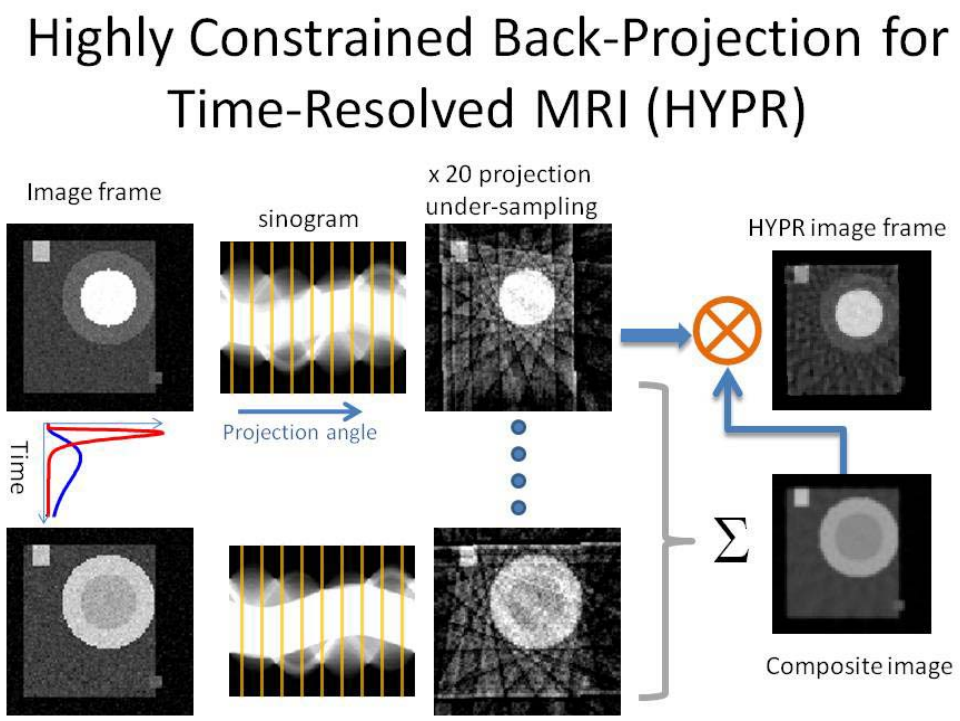

Figure 3: *Highly constrained back-projection for time-resolved MRI is based on sparse radial undersampling. A sliding window is used to define a complete set of radial samples and reconstruction of a "composite" image (i.e. from data acquired over several cardiac cycles). This composite image is used as a constraint to reconstruct the individual frames from the radially undersampled data. The example shows x20 under-sampling of a computer generated phantom.*

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