Evaluation of Myocardial Perfusion Research Promises: What Can We Expect in the Future?

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Introduction Myocardial stress perfusion MRI is an effective method for the detection of coronary heart disease. The recent CE-MARC trial demonstrated that MR stress perfusion using currently established techniques is more accurate than SPECT [1]. This presentation will focus on emerging techniques that may further improve myocardial perfusion MR.

Established methods for contrast perfusion MR still have somewhat limited spatial resolution, temporal resolution and spatial coverage. Moreover, they sometimes suffer from dark rim artifacts, which are likely caused by some combination of Gibb's ringing, cardiac motion, and off-resonance effects. Thus, the first part of this talk will focus on emerging methods for rapid myocardial perfusion imaging, which can be used for improved resolution and greater spatial coverage. Many of these methods enable whole-heart perfusion imaging and thus assessment of ischemic burden [2]. This presentation will cover two broad classes of rapid imaging methods: non-Cartesian scanning and spatiotemporal acceleration methods.

Another limitation of contrast perfusion MR is that patients with impaired renal function may not be eligible to receive gadolinium contrast, because of the risk of nephrogenic system fibrosis. In those patients, a non-contrast perfusion method may be valuable. The presentation will also include a discussion of recent progress in non-contrast perfusion imaging using arterial spin labeling (ASL).

Non-Cartesian Scanning One option for speeding up data acquisition is to acquire the k-space data using a non-Cartesian trajectory. Both radial and spiral trajectories have been studied for first-pass perfusion imaging. One advantage of these methods is that they are relatively robust in the presence of motion, because the high-energy center of k-space is sampled in every readout and because any remaining motion artifacts are spread in an incoherent fashion, rather than as coherent ghosts. This motion robustness can be valuable in suppressing respiratory artifacts in some acquisition schemes and may prove useful in reducing dark rim artifacts.

Radial scanning typically achieves scan time reduction by undersampling the outer portion of k-space. The resulting aliasing artifacts then have relatively low energy. These artifacts can be further suppressed using spatiotemporal acceleration methods [3]. Spiral scanning achieves scan time reduction by scanning more of k-space after each excitation. Constant-density spiral scanning can produce high-quality perfusion images [4, 5], even without using additional acceleration methods, such as undersampling or parallel imaging. By also incorporating undersampling, parallel imaging methods and spatiotemporal acceleration methods, both radial and spiral methods can be extended to collect volumetric perfusion data. In many of these methods, the increased sampling of the center of k-space in radial and variable-density spiral trajectories can be useful in acquiring calibration or training data.

Spatiotemporal Acceleration Techniques Parallel imaging methods, such as SENSE and GRAPPA, are now widely used for perfusion imaging, typically with an acceleration factor of 2 [6]. TSENSE

is a widely used parallel imaging method that dynamically acquires calibration data using a time-interleaved approach, which eliminates the need for separately acquiring reference data [7]. With a three-dimensional acquisition, this method can yield an acceleration factor of 6 for perfusion imaging [8].

More recently, high acceleration factors have been achieved using methods that exploit the high correlation between successive temporal frames in a perfusion data set, often in conjunction with parallel imaging. Here we refer to such methods spatiotemporal acceleration techniques. One broad class of spatiotemporal acceleration techniques are those related to kt-SENSE [9]. As described well in [10], these methods pack and recover signal content in x-f space, using knowledge of the coil sensitivities and using low-resolution training data sampled at the full temporal rate. One early study of these methods for imaging myocardial perfusion used a net acceleration factor of 3.9 [11]. A somewhat related method called PEAK-GRAPPA yielded an acceleration factor of 3.4 [12]. Newer methods related to kt-SENSE have yielded acceleration factors of 5.8 in two dimensions [10] and 10 in three dimensions [2].

Another class of spatiotemporal acceleration techniques are those based on exploiting the sparsity of the information in a time series of images, where there is relatively little change in most of the image from one temporal frame to the next. These techniques have been called temporally-constrained reconstruction (TCR) techniques, but more recently are typically referred to as compressed sensing (CS) techniques. The general idea of these methods is to mathematically transform the acquired data into another domain where it has a sparse representation, and then to assume that the low-intensity coefficients in that domain can effectively be ignored. For example, simply taking the difference between successive images is one such transform. This sparsity is then used in an iterative image reconstruction method to effectively fit the reconstructed image to the acquired data. These TCR and CS methods have been applied to perfusion at high acceleration factors with excellent results [3,13,14]. One interesting aspect of these methods is that they can often maintain high signal-to-noise ratios at these acceleration factors, because of the nature of the iterative reconstruction method. One limitation of these methods is that they can suffer from image blurring or artifacts when the patient breathes, although work is ongoing to incorporate non-Cartesian k-space trajectories and motion compensation methods to reduce or eliminate these effects.

Arterial Spin Labeling ASL is a non-contrast perfusion imaging method that has been applied to imaging the brain and kidney. The basic idea of ASL is to acquire two images of the area of interest, with the magnetization of the upstream blood prepared using RF pulses. The magnetization preparation (typically an inversion pulse) varies between the two images, and the difference of the two images yields a perfusion map after appropriate processing. ASL generates difference signals of only a few percent, so it is challenging to acquire reliable perfusion images in a short scan time, especially in the presence of cardiac and respiratory motion [15]. However, recently two groups have produced promising results in myocardial ASL, using both a multiple-breath-hold approach [15, 16] and a navigator-echo approach [17]. In one of these studies, ASL was shown to detect reduced perfusion reserve in ischemic segments of patients with angiographically proven coronary artery disease compared with patients shown not to have CAD [16]. There are still significant challenges to be overcome before this technique is ready for use in individual patients, but the early results are encouraging [18].

Summary Myocardial perfusion MRI is an established technique with excellent accuracy. New methods of perfusion MRI promise to deliver higher spatial resolution and volumetric acquisition, using a combination of advanced image acquisition and image reconstruction methods. Noncontrast myocardial perfusion MRI is still in its early stages, but arterial spin labeling methods show promise.

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