MR Physics for Clinicians /Ultrafast Imaging

Mariya Doneva, PhD mariya.doneva@philips.com

Objectives: Understand the principles of ultrafast MRI methods.

Purpose: Fast MR imaging techniques are needed to reduce the risk of motion artifacts, improve the spatial or temporal resolution, or increase the patient throughput. This lecture aims at giving an overview of the methods for fast MR acquisition including fast imaging sequences, such as EPI, and techniques for acquiring reduced amount of k-space data such as partial Fourier and compressed sensing.

Methods: Assuming that the image field of view (FOV) and resolution are selected, there are two fundamental strategies to speed up the acquisition: 1) improving the sampling efficiency, in other words acquiring more data in less time and 2) collecting less data and using prior knowledge to recover the missing data. While these techniques offer significant scan time reduction, they are often sensitive to artifacts that may degrade the image quality.

The basic concept underlying all fast (or ultrafast) imaging sequences is to cover the k-space as quickly as possible. This is typically achieved by acquiring more data for each repetition time while reducing the number of repetitions, thereby shortening the total scan time. The two most popular approaches are echo-planar imaging (EPI), which acquires data on an alternating zig-zag trajectory through k-space, and spiral imaging, which acquires data on a curved line in k-space. In the extreme case, the complete trajectory can be acquired in a single TR, which is called single shot acquisition.

Unfortunately, the MR signal is not constant for the duration of the TR. Causes for signal variations include signal attenuation (T2, T2* decay), constructive and destructive interferences between water and fat signals (chemical shift), local variations of the magnetic field, blood flow, patient motion, etc. By increasing the readout window, parts of the data matrix will be filled with data from an earlier echo time, while others will come from a later echo time. Conceptually, this is equivalent to mixing parts from different images to form a single image. This data mismatch increases with increasing time spent per TR to acquire data, and may result in image artifacts. Another possible source of artifacts is instrumentation. As the imaging speed is pushed to its limits slight errors in timing or gradient switching may result in a mismatch between the intended and the actual k-space locations at which data are acquired. The actual appearance of the artifacts depends on the applied k-space trajectory; therefore it will be different for a zig-zag trajectory such as in EPI and non-Cartesian trajectories such as spiral.

The acquisition speed can be further pushed by collecting less data and reconstructing the image using prior knowledge. Common techniques include partial Fourier acquisition and keyhole imaging. Recently, many more methods for MR reconstruction using incomplete data have emerged in conjunction with compressed sensing. Accelerating the image acquisition by reducing the amount of acquired data comes at the price of a reduced SNR. Further issues may arise due to a mismatch between the data and the applied prior knowledge.

Discussion and Conclusion: Imaging speed can be gained by making pulse sequences as efficient as possible and acquiring only as much data as needed. Increasing the imaging speed may increase the sensitivity to artifacts or decrease the SNR. Careful consideration of these limitations in pulse sequence design, application of artifact correction methods, and appropriate reconstruction techniques allow fast and robust imaging in the clinical setting.

References:

1. Tsao J. Ultrafast imaging: principles, pitfalls, solutions, and applications. J Magn Reson Imaging 32(2):252-66, 2010.
2. Mistretta CA. Undersampled radial MR acquisition and highly constrained back projection (HYPR) reconstruction: potential medical imaging applications in the post-Nyquist era. J Magn Reson Imaging 29(3): 501-16, 2009.