Technical Advances in Cardiovascular Imaging - Parallel Imaging

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Highlights:

- Introduction to parallel imaging techniques in the context of parallel imaging.
- Overview of the central role parallel imaging plays in cardiac imaging.
- Examples of applications that have been enabled or improved by parallel imaging.

TARGET AUDIENCE: Scientists and clinicians who would like to understand the role of parallel imaging in cardiovascular MRI.

OBJECTIVES: This course will enable attendees to understand the basics of the parallel imaging techniques used in cardiovascular MRI. Based on this knowledge, it will be possible to identify successful strategies for using parallel imaging in cardiovascular MRI. The attendees will gain insight into the central role that parallel imaging plays in cardiac imaging and how almost every cardiac imaging acquisition has been improved in some way by the introduction of parallel MRI.

PURPOSE: Cardiac MRI is under acquisition time constraints due the continuous motion of the heart. The heart is affected by both cardiac contractile motion and respiratory motion. While both sources of motion can be compensated for by cardiac gating or breath-holding respectively, there are physiological limits to the amount of data that can be acquired. These constraints affect virtually every cardiac imaging application. Shortly after the introduction of parallel imaging [1–3], it was applied to cardiac imaging [4] with great success and since almost all cardiac imaging applications have been improved by the use of parallel imaging.

METHODS: The objective of the MRI experiment is to collect enough raw data to reconstruct an image with the desired field of view and resolution. In the case of cardiac imaging, we wish to image a moving structure with moderate to high spatial and temporal resolution, which puts specific time constraints on the imaging experiment. While great improvements in imaging speed have been achieved with steady state free precession (SSFP) sequences and fast switching gradients, there is still a need to go faster. Parallel imaging has provided a way to accelerate almost all cardiac imaging applications. In this lecture, we will review the basics of parallel imaging and discuss how parallel imaging is applied to a set of example applications.

In this lecture, the Cartesian parallel imaging procedure will be described as a phased array combining procedure where aliased images from multiple receiver channels are combined (linearly) to obtain images that are a) alias free, and b) SNR optimal. There are multiple ways to obtain the required coil combination coefficients. The most commonly used techniques are SENSE [5] and GRAPPA [3]. We will review how these techniques use calibration data to obtain coil combination (or unmixing) coefficients. If the scaling is carefully controlled throughout the reconstruction, these unmixing coefficients can be used to directly determine the signal to noise ratio in the reconstructed images [6]. In cardiac imaging, the need for calibration data can add significantly to the acquisition time, but since we often acquire multiple frames of the heart, the repeated measurements (or time frames) can be used to obtain calibration data with little or no overhead [7].

Typical series of cardiac images contain multiple frames covering the cardiac cycles. Such image series have inherent redundancies since only a portion of the image is actually moving. This has been exploited to accelerate cardiac parallel imaging even further. Examples of techniques that exploit this feature include *k-t* SENSE [8] and *k-t* GRAPPA [9], which have been explored extensively for cardiovascular imaging. In this lecture, we will review the basic properties of these techniques and why they may be particularly suitable for cardiac imaging.

The use of parallel imaging in cardiovascular MRI is not restricted to Cartesian sampling. Parallel imaging can be applied to non-Cartesian sampling as well [10]. Some non-Cartesian sampling patterns, such as radial sampling or golden angle radial sampling [11], have properties that may be particularly useful for parallel imaging. One of the main obstacles for using non-Cartesian parallel imaging for cardiac MRI (or in general) has been the lengthy reconstruction time associated with such acquisitions. Recently advances have been made towards reducing the reconstruction time [12, 13] for these applications and in this lecture we will review some of the used techniques and the research promise associated with them.

Using the theoretical foundation outlined about, this lecture will review the role of parallel imaging in a) evaluation of cardiac function, b) quantification of flow, c) perfusion imaging, d) late gadolinium enhancement, and e) parametric mapping. All of these applications have benefitted from (or been directly enabled by) parallel imaging.

CONCLUSION: Parallel imaging plays a critical role for almost all cardiac imaging methods. This lecture reviews the basic techniques and their impact on a subset of the commonly used cardiac imaging methods.

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