Specialty Area: Fast Cardiac Imaging

Speaker Name: Daniel Kim (daniel.kim@hsc.utah.edu)

Highlights:

- k-t acceleration methods leverage data redundancy (i.e., similarity among temporal frames) inherent with dynamic MRI acquisitions
- High acceleration factors can be used to increase the spatio-temporal resolution and/or reduce scan time
- Example cardiac MRI applications include cine MRI, first-pass perfusion MRI, phase-contrast MRI, and T1/T2/T2* mapping

Title: k-t Based Acceleration Methods

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 high acceleration with dynamic MRI
- Understand presently known k-t acceleration methods, as well as their advantages and disadvantages
- Understand why cardiac and respiratory motion is a major challenge for k-t acceleration methods
- Appreciate the benefits of k-t acceleration methods (when they actually work!)

Purpose/Introduction: Dynamic cardiovascular MRI applications such as cine MRI (1-3), first-pass perfusion MRI (4-7), phase-contrast MRI (8-13), and myocardial relaxometry (T1/T2/T2*)(14-18) provide clinically useful information. Because the heart and diaphragm moves with cardiac and respiratory cycle, respectively, these dynamic MRI acquisitions are typically performed with ECG triggering and breath holding to minimize motion artifacts. This constraint limits the amount of information (i.e., spatial resolution, temporal resolution, spatial coverage) that can be obtained with conventional dynamic MRI acquisitions. As well, this constraint decreases the clinical throughput; typical clinical cardiovascular MRI protocols comprised of a suite of image acquisitions can take as long as 45-60 min to complete. For improved clinical workflow, it is important to accelerate what are otherwise slow scans.

These limitations can be addressed directly with fast imaging techniques, such as non-Cartesian acquisitions, dynamic parallel imaging, and k-t acceleration methods. This presentation will cover only the k-t acceleration methods; they can be classified into two broad categories: linear and non-linear constrained reconstruction. Linear reconstruction methods include k-t BLAST (19), k-t GRAPPA (20), and k-t SENSE (19); these methods have the advantage of faster reconstruction speed but have the disadvantage of comparatively lower acceleration rate. Nonlinear reconstruction methods in the compressed sensing (CS) (21) framework include k-t SPARSE (22), k-t SPARSE-SENSE (23), k-t FOCUSS (24), k-t PCA (25), k-t SLR (26), and k-t GROUP SPARSE (27); these methods have the advantage of comparatively higher acceleration rate but have the disadvantage of slower image reconstruction speed. For more details on key factors that are critical for k-t acceleration methods and CS, please see (28, 29).

This presentation will highlight the importance of fast imaging techniques that will ultimately enable wider adoption of cardiovascular MRI into clinical practice. This presentation is aligned with the theme promoted by the 2014 SCMR/ISMRM workshop entitled, ”*Accelerated CMR: Towards Comprehensive Clinical Cardiovascular Imaging*.”

Methods: The sampling theory teaches us that k-space undersampling produces aliasing artifacts. It turns out that the resulting aliasing artifact is directly related to the specific undersampling pattern. The user, then, is able to control how the aliasing artifacts are spread over the desired domain (e.g., x-f space) in a way that is easy to remove them using either linear or nonlinear constraint reconstruction. Figure 1 shows a schematic of how k-t BLAST/SENSE works. In this linear reconstruction framework, a training data set needs to acquired as a prior information. The actual data set is undersampled in a regular fashion (typically lattice like), which will produce coherent aliasing artifacts. Finally, aliasing artifacts are removed using an l-2 regularization. Unlike k-t BLAST/SENSE/GRAPPA, in the CS (21) framework, the sampling pattern needs to be random (see Figure 2) to generate incoherent aliasing artifacts (pseudo-noise like in appearance). Then the goal is to identify a sparse domain (e.g., x-f space) in which the artifacts can be easily filtered from the true signal using an iterative l-1 regularization. Typically, the user must tune the regularization weight to achieve optimal results; the weights will depend on the data content (sparse domain) and sampling pattern.

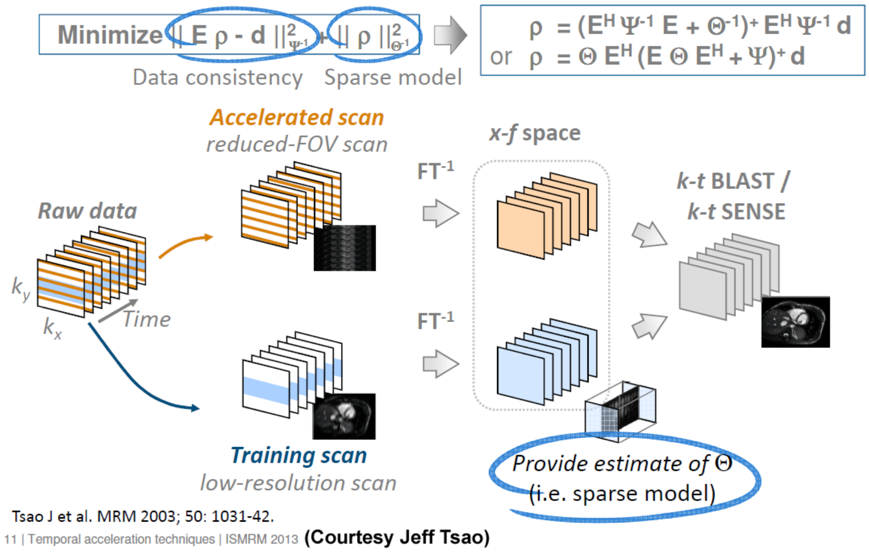

Figure 1. Schematic of k-t BLAST/SENSE.

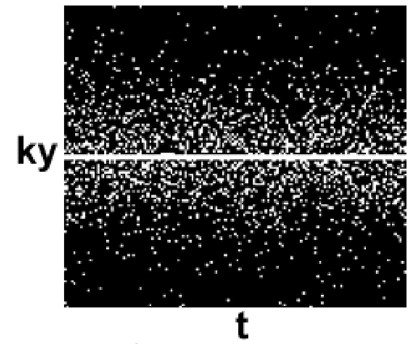

Figure 2. Semi-randomized k-space sampling pattern for CS. Unlike regular sampling patterns, randomized sampling patterns produce incoherent aliasing artifacts. These are then filtered from the true signal with an l1 regularization.

Results: The following are example images rapidly acquired with CS. Figure 3 shows cine images of a patient in persistent atrial fibrillation (challenging setting). Real-time cine images acquired with CS had higher spatial (1.9 x 1.9 mm) and temporal resolution (36 ms), as well as image quality (note particularly the endocardial border definition, as well as the spatial-temporal intensity profiles), than commercial real-time cine images acquired with TGRAPPA (spatial resolution = 2.6 x 3.3 mm; temporal resolution = 108 ms). Figure 4 shows perfusion images (spatial resolution 2 mm x 2 mm x 8 mm and temporal resolution of ~45 ms) acquired with CS (30). This acquisition also includes self-binning and motion correction, whose effectiveness are enhance with rapid speed afforded by CS (i.e., synergistic).

Discussion: k-t acceleration methods can be used to increase the spatio-temporal resolution and/or reduce scan time. Both linear and nonlinear constrained reconstruction methods have advantages and disadvantages. Both methods are also compatible with non-Cartesian sampling patterns such as radial (31-35) and spiral (36). As computing technology improves, nonlinear constrained reconstruction times may become more clinically practical. More work is needed to optimize these reconstruction methods and evaluate their performance in a clinical setting.

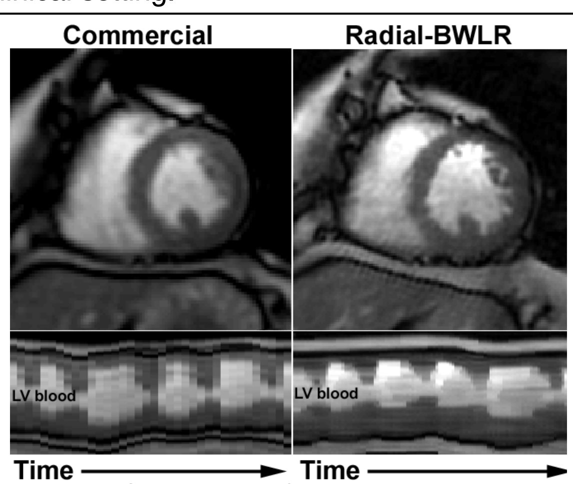

Figure 3. Cine images of a patient with persistent atrial fibrillation: commercial TGRAPPA (left) and highly-accelerated CS (right).

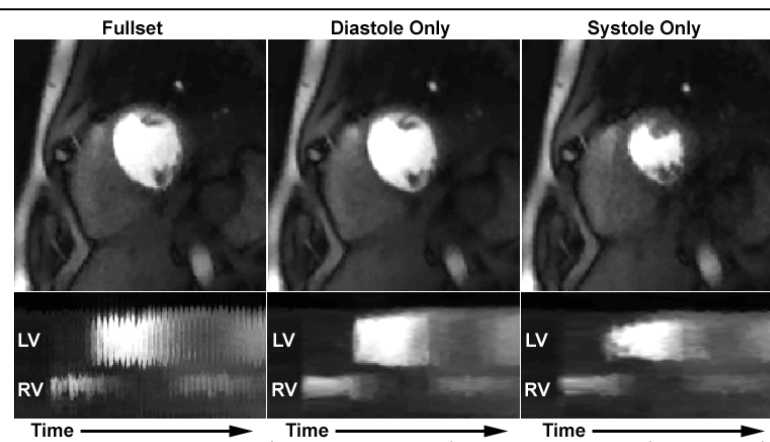

Figure 4. Ungated perfusion images of a volunteer: all frames (left), diastole only (middle), and systole only (right). Diastolic and systolic subsets with motion compensation were interpolated through time, in order to match the number of frames of the full set. Spatial-temporal intensity profiles reflect improvement with motion correction. RV/LV: right/left ventricular cavity.

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