k-t SPEEDER: A Reference-Free Parallel Imaging Method for Fast Dynamic MRI

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Highlight

k-t SPEEDER is a reference-free parallel imaging method that exploits spatial-temporal correlation to further accelerate dynamic MRI scans compared to parallel imaging method. That in turn enables enhanced patient comfort and productivity with quality images.

Background

Dynamic MRI is an imaging technique in which a target organ is imaged repeatedly to produce time-resolved image series. The time-resolved images provide information beyond anatomy that includes function and physiology. One common application of dynamic MRI is cardiac Cine that is considered as the gold standard for assessment of the ventricular function, volumes, mass, and ejection fraction.[1] Conventional cardiac Cine often requires long and repeated breath-holds that in turn leads to lengthy cardiac MR exams, patient discomfort, and sensitivity to motion artifacts. Additionally, heart rate variation and arrhythmia are other challenges in cardiac Cine that often leads to sub-optimal or even non-diagnosable image quality. The physical (gradient strength and slew rate) and physiological (peripheral nerve stimulation) constrains limit how fast a fully sampled MR data can be acquired. Therefore, parallel imaging has been used to accelerate MR scans by exploiting spatial correlations and redundancies in data acquired from multiple receiver coils.[2–5] The spatial redundancies allow parallel imaging to reconstruct images with less data, resulting in fast scans. In dynamic imaging, both spatial and temporal correlations and redundancies in data can be exploited to further accelerate MR scans, namely k-t acceleration techniques.[6] In such k-t methods, additional reference training data is often required to unfold the under-sampled data. The acquisition of training data limits overall achievable acceleration factor. Canon Medical introduces k-t SPEEDER[7], a reference-free k-t acceleration technique that doesn't require additional reference training data. The speed gain in k-t SPEEDER directly translates to shorter breath-hold duration, or shorter CMR exam, or improved spatial and temporal resolution.

Technical Description

Under-sampling pattern of k-t SPEEDER

In k-t SPEEDER, k-space data in each time frame is under-sampled in phase encoding direction and the under-sampling pattern is shifted in the next time frame. This sampling strategy spreads aliasing artifacts in both directions (space and time) allowing better utilization of both spatial and temporal redundancies as seen in **Figure 1**. That in turn leads to better reconstruction compared to the under-sampling pattern without the shifts in the temporal direction.

k-t SPEEDER: A reference-free parallel imaging method

Pre-acquired or auto-calibrating fully sample reference data is often required for reconstruction of under-sampled k-t data as seen in k-t BLAST and k-t SENSE techniques.[6]

Instead of using training data, k-t SPEEDER uses estimated coil sensitivity maps in the x-f space to un-wrap aliasing artifacts. Avoiding acquisition of reference data allows k-t SPEEDER to achieve higher *effective* acceleration compared to techniques that require reference data as seen in **Figure 2**. The x-f coil sensitivity maps are estimated directly from under-sampled k-t data using motion-independent approximation with motion-dependent mask in x-f data.[7] Once the x-f coil sensitivity maps are estimated the reconstruction is very much similar to the SPEEDER reconstruction.[2]

Clinical Applications

The utilization of spatial and temporal redundancies allows k-t SPEEDER to achieve higher acceleration factor compared to parallel imaging methods while maintaining comparable image quality. The higher achievable acceleration from k-t SPEEDER could be used to improve spatial/temporal resolution, reduce exam duration, and increase patient comfort and throughput. Below are suggested benefits and use cases of the prospective k-t SPEEDER (acceleration factor of 4) compared to the prospective SPEEDER (acceleration factor of 2) technique.

Benefits of k-t SPEEDER

- Provides higher effective scan time acceleration
- Improves patient comfort and throughput by shortening breath-hold duration and scan time
- Improves spatial and temporal resolution
- Less susceptible to motions

Shorter breath-hold duration

In Cine CMR, the time saving from higher acceleration in k-t SPEEDER could be used to shorten the breath-hold compared to the SPEEDER sequence. That improves patient comfort while maintaining diagnostic image quality. This use case is beneficial when imaging patients who have difficulty in holding their breath. **Figure 3** shows images at systolic and diastolic phases acquired from 4X k-t SPEEDER and 2X SPEEDER. The breath-hold duration was halved from 12 to 6 seconds using k-t SPEEDER.

Increased temporal resolution

Given the time saving using k-t SPEEDER, temporal resolution of Cine CMR can be improved while maintaining comparable scan time and breath-hold duration. Higher temporal resolution may allow more

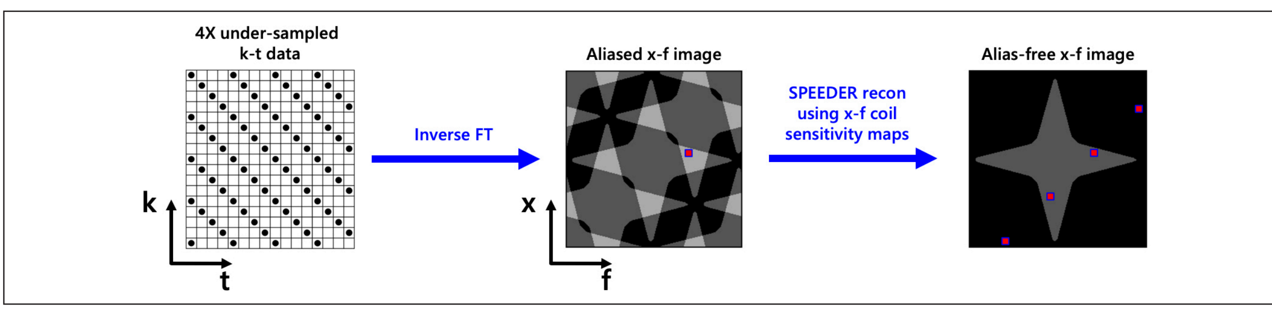

Figure 1. An illustration of a 4X k-t SPEEDER under-sampling pattern (left) that results in aliased image in the x-f space (middle) after an inverse Fourier Transform (FT) in both spatial and temporal directions. Given the under-sampling pattern, a pixel on the aliased image is the overlap of 4 pixels in the alias-free image (right). Similar to SPEEDER parallel imaging method, the aliased image can be unfold using estimated coil sensitivity maps in the x-f space.

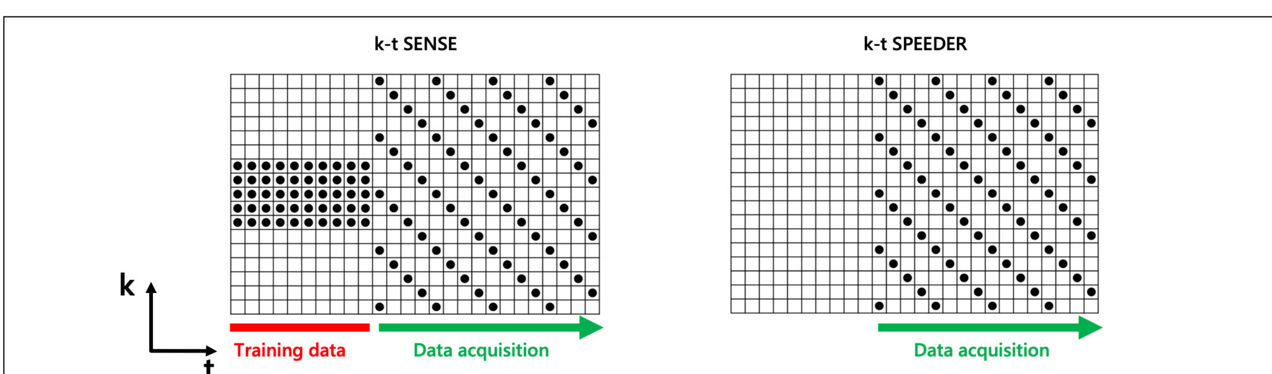

Figure 2. Higher effective acceleration factor can be achieved by k-t SPEEDER since it does not require a reference training data.

accurate function assessment and motion tracking because of better depiction of temporal changes as pointed by the arrows in **Figure 4**.

Shorter exam duration

Another application of k-t SPEEDER is to shorten the total scan time by acquiring multiple slices in one breath-hold while maintaining comparable breath-hold duration to SPEEDER. That enables increased throughput and patient comfort with comparable image quality and quantitative measures. In one of the clinical studies[8,9], 2X SPEEDER and 4X k-t SPEEDER were performed on 18 healthy volunteers and 38 patients demonstrating an average of 58% reduction in Cine CMR acquisition with comparable image quality image quality and quantitative measures such as left ventricular ejection fraction (LVEF), left ventricular end-diastolic volume index (LVEDVI), left ventricular end-systolic volume index (LVESVI), and left ventricular mass index (LVMI. As seen in **Figure 5**, LVEF measured from SPEEDER and k-t SPEEDER are highly correlated (r = 0.95) and in good agreement (bias = 1.34%,

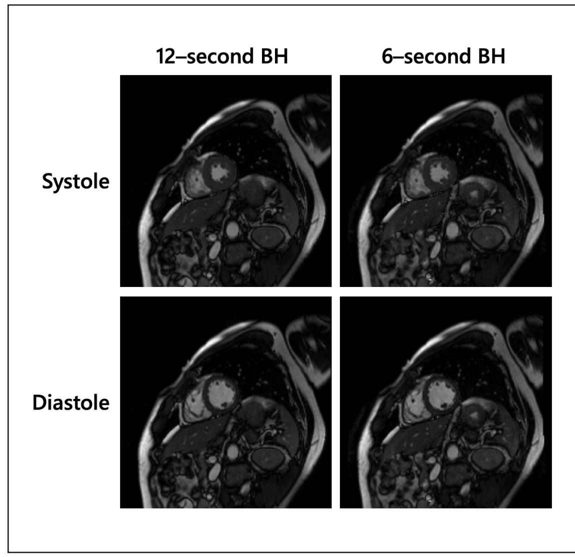

Figure 3. Representative systolic (top row) and diastolic (bottom row) phases acquired from 2X SPEEDER (left column) and 4X k-t SPEEDER (right column). The breath-hold duration is halved from 12 to 6 seconds in k-t SPEEDER with comparable image quality and spatial-temporal resolution.

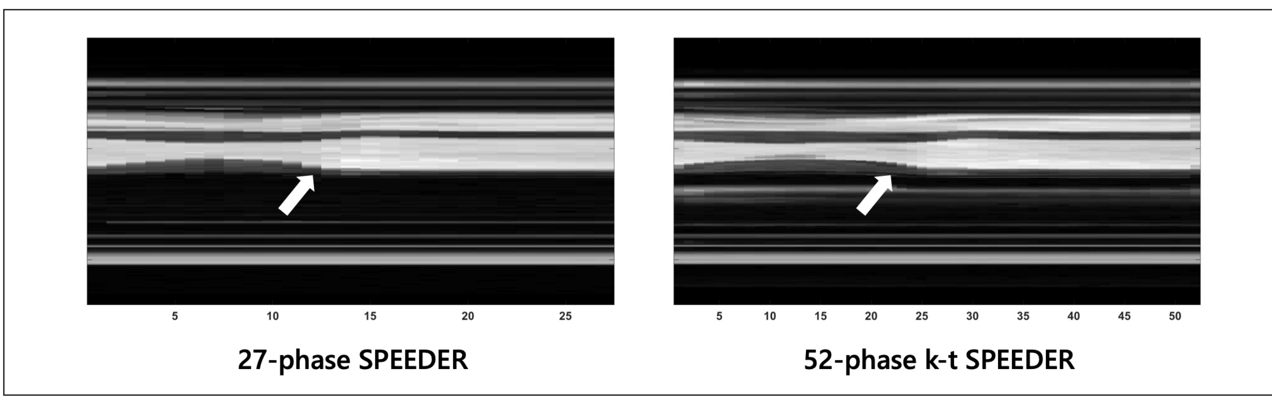

Figure 4. k-t SPEEDER doubles temporal resolution while maintaining image quality, spatial resolution, and breath-hold duration as compared to SPEEDER. Higher temporal resolution may allow more accurate function assessment and motion tracking because temporal changes are better depicted as pointed by the arrows.

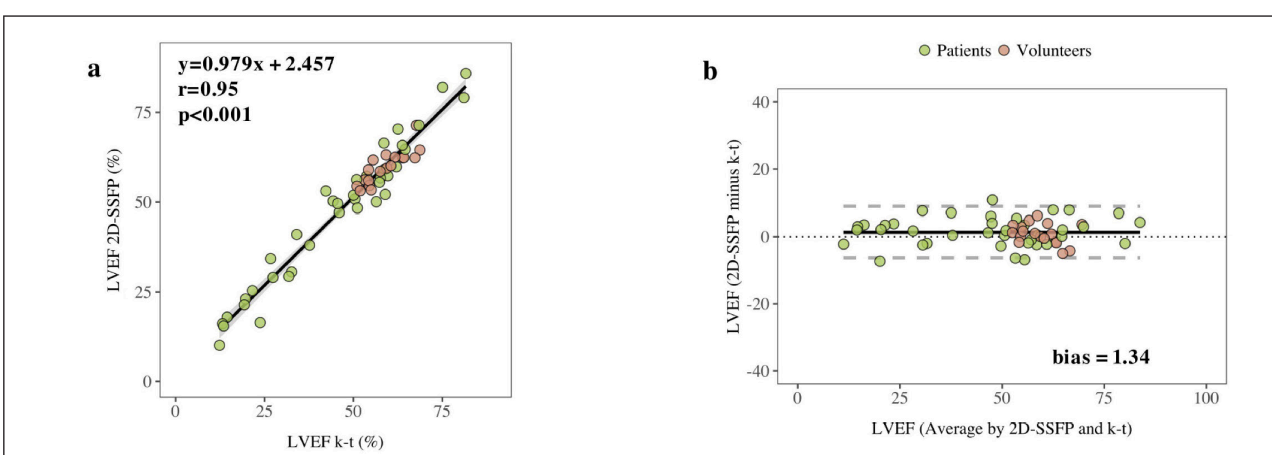

Figure 5. LVEF measured from SPEEDER and k-t SPEEDER are (a) highly correlated (r = 0.95) as seen in the linear regression plot and (b) in good agreement (bias = bias = 1.34%, limits of agreement = (-6.26%, 8.95%)) as seen in the Bland-Altman plot.

limits of agreement = (-6.26%, 8.95%)). Dr. Cesar Nomura, MD, PhD, (Director of Radiology Department at the University of São Paulo, and USP · Instituto do Coração (InCor)) commented that "k-t SPEEDER sequence is feasible and can accurately quantify LV volumes, function and mass, with a considerable shortening of acquisition time (lowering the number of breath-holds) and good image quality. k-t SPEEDER may be an accurate alternative for CMR image acquisition especially in patients for whom shorter imaging times are desirable."

Summary

In summary, k-t SPEEDER is an efficient parallel imaging technique that exploits both spatial and temporal redundancies to accelerate the dynamic MRI scan allowing higher achievable acceleration compared to parallel imaging techniques that only utilize spatial redundancy. Furthermore, k-t SPEEDER is a reference-free parallel imaging technique, therefore, it provides a higher effective acceleration factor compared to its k-t counterparts. This whitepaper describes that higher acceleration achieved by k-t SPEEDER could be used to improve patient comfort and throughput of the Cine CMR.

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