Undersampled 3D UTE FID Sequences: Cones Vs. PR

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Introduction: Imaging short T2 tissues frequently encountered in the musculoskeletal system using MRI requires specialized pulse sequences with very short echo times (TE). The common feature of many ultrashort TE (UTE) sequences is that data acquisition is started as soon as possible after the RF excitation, and k-space is acquired in a center-out fashion. There have been several k-space trajectories employed for UTE imaging, such as radial-out projection acquisition (PR) [1], acquisition-weighted stack of spirals (AWSOS) [2], twisted projection imaging (TPI) [3], and Cones [4]. Spiral-like acquisitions provide high data collection efficiency per unit time at the expense of sensitivity to dephasing during the data acquisition readout. Radial out sequences on the other hand are less efficient but have less sensitivity to dephasing. Non-Cartesian trajectories provide the flexibility to undersample k-space to accelerate the acquisition time at the expense of undersampling artifacts. Undersampled straight, radial-out PR trajectories often exhibit only mild diffuse streaking artifacts, while undersampling of more curved, spiral-like trajectories (alike to circular rings) causes more severe artifacts [5]. Here we investigate via theoretical analysis and phantom experiments the tradeoffs in terms of scan-time and image quality (aliasing artifact and SNR) between Cones (see Fig.1) and PR.

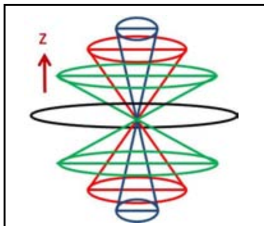

Fig.1: Cones surfaces. K-space trajectories originate at the center and move outwards either straight or curved. Several degrees of curvature for trajectories on the equator Cones plane (black) are shown in Fig.2A.

Numerical simulations: Point Spread Functions (PSFs) were generated for four different trajectory lengths, ranging from a pure PR (readout duration 624µs), trajectories with more twist (readout duration 680-1600µs), to a more spiral-like trajectory with many full turns within one spoke (readout duration 4000µs). The last trajectory only serves for comparison purposes, since such long trajectories introduce undesired T2* blurring for short T2 tissues. The k-space trajectory simulations are based on a fixed short scan-time of 55 sec, isotropic FOV = 24cm, and res = 1mm. Indicated in Fig.2A are the undersampling factors ('under') required to achieve the same scan-time. This factor is multiplied with the desired FOV, so that the number of spokes reduces by the square of the under sampling factor (e.g. under = 0.5 results in a reduction in spokes by a factor of four). The PSFs are shown in Fig.2B at twice the FOV (48cm) of the reconstructed images (indicated by the dashed boxes), and at the same adjusted window level in order to emphasize aliasing signal in the region outside the supported area. The high undersampling for the PR trajectory results in only a small region of support surrounded by diffuse radial streaks, while the longer trajectories result in a larger region of support, but have more coherent aliasing signal just outside that region. Finally, from sampling theory in MR, an expected advantage for longer trajectories should be increased SNR.

Phantom Experiments: A standard resolution phantom was imaged using a clinical 3T MRI system (Signia HDx GE Healthcare) with a T/R head coil. Acquisition parameters included BW = ±125kHz, isotropic FOV = 24cm and resolution = 1mm, using TE = 30µs, and total scan-time of 55 seconds. For the first three trajectories, the TR was fixed to 5ms (the minimum for the 1600 µs trajectory), while the TR for the last acquisition had to be increased to TR = 7.3ms. This means that the total number of k-space spokes was identical for the first three trajectories. The symmetry axis of the Cones design was along z, perpendicular to the axial images shown in Fig.2C,D. These images were also reformatted into the coronal plane as shown in Fig.2E,F, which lie in the same plane as the PSFs. Two distinct artifacts can be observed: The images generated by the very short PR trajectory and highest degree of undersampling results in visible streaking artifacts (red oval). On the other extreme, the image using a very long readout trajectory (last row) results in less visible aliasing artifacts but causes some blurring near the edge of the phantom (see also Fig.2G). The trajectory in the second row shows reduced artifacts compared to pure radial, without the significant blurring seen in the very long readout trajectory. Finally, the SNR in the images from the longer trajectories is visibly higher than the shorter trajectories, as expected.

Conclusion: We have investigated the image quality and SNR tradeoffs between trajectory length and undersampling for Cones and PR sequences. Undersampling artifacts were found to dominate in the images from the very short acquisition trajectories, whereas blurring was found to be significant in the very long spiral-like trajectories. An intermediate Cones trajectory was found to provide a good balance to optimize image quality. In our studies, we chose to keep the same TR (for the first three trajectories) when comparing different k-space trajectories. In principle, shorter gradient waveforms (e.g. PR) would allow for a shorter TR and hence allow for more trajectories within the same scan-time. However, this effect becomes negligible with the inclusion of long contrast generating preparation pulses such as fat saturation or inversion recovery that dominate the total TR time. Without these preparation pulses, the artifact vs. scan-time advantage would shift further towards the shorter PR-like trajectories.

References: [1] Rahmer et al. MRM 55:1075–1082 (2006), [2] Qian et al. MRM 60:135–145 (2008), [3] Boada et al. MRM 37:706-715 (1997) [4] Gurney et al. MRM 55:575-582 (2006), [5] Scheffler et al. MRM 40:474-480 (1998),

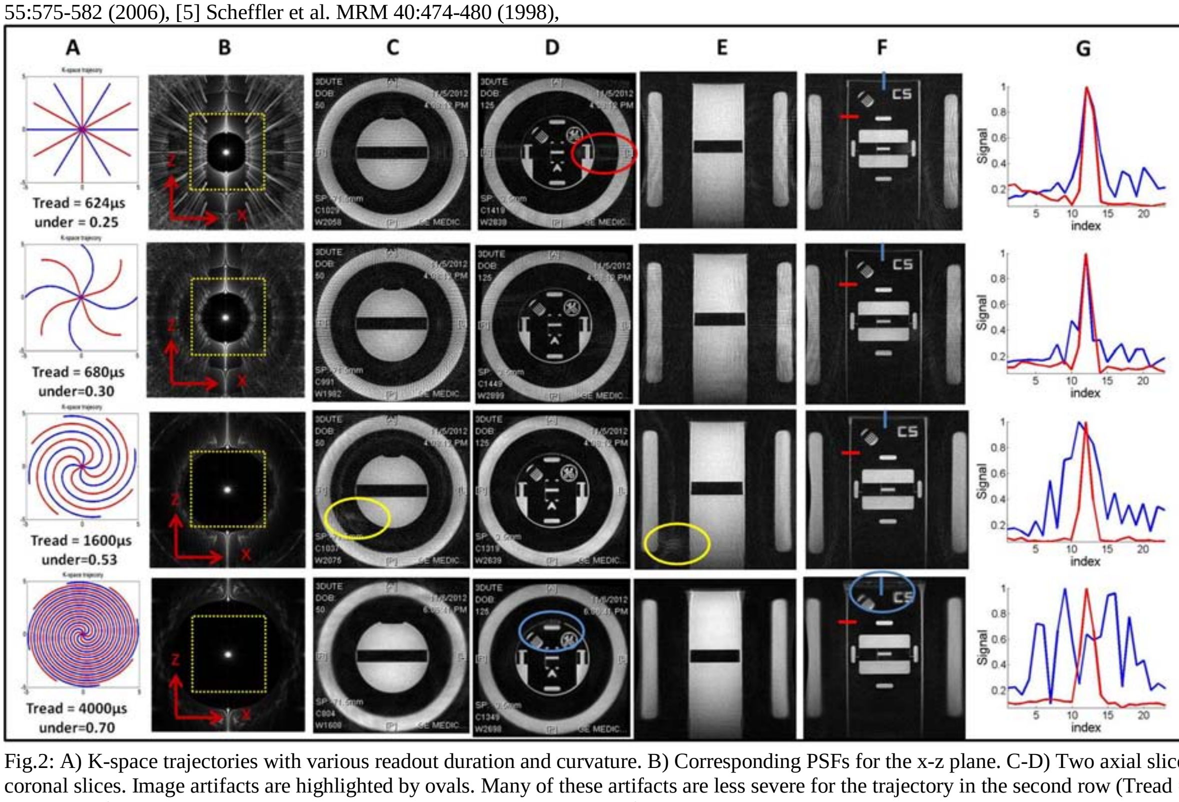

Fig.2: A) K-space trajectories with various readout duration and curvature. B) Corresponding PSFs for the x-z plane. C-D) Two axial slices. D-E) Two reformatted coronal slices. Image artifacts are highlighted by ovals. Many of these artifacts are less severe for the trajectory in the second row (Tread = 680µs). G) 1D lines through two walls of the phantom (as indicated in F), showing increased blurring for longer trajectories.