

High Resolution Cartilage and Whole Organ Knee Joint Assessment: 3D Radial Fat-Suppressed Alternating TR SSFP

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INTRODUCTION Effective cartilage imaging and whole organ joint assessment requires both high isotropic resolution and fat suppression or separation. SSFP lends itself to this task as it rapidly creates high signal-to-noise ratio (SNR) and T2-like contrast with bright fluid signal. However, SSFP also produces bright fat signal which may interfere with visualization of the critical cartilage/bone interface. Here we propose a single pass, 3D radial fat-suppressed Alternating TR (FS-ATR) SSFP acquisition which provides ultra-high isotropic resolution of 0.33 mm (voxel volume of 1/27 mm³) throughout the entire knee joint. The radial trajectory provides significantly higher resolution than a Cartesian trajectory could provide within the TR constraint. We contrast the method against a two pass, 3D radial Linear Combination SSFP (LC-SSFP) method [1]. The benefit from not redundantly sampling data and reducing off-resonance blurring are demonstrated in the depiction of minute, focal cartilage defects at ultra-high isotropic resolution.

METHODS Fat-suppressed ATR [2] uses two different alternating length TRs with a TR2:TR1 ratio of 1:3 and RF phase cycling to shape the spectral frequency response to place a stopband over the fat resonance (Figure 1). When applied to a conventional 3D Cartesian trajectory with ramp sampling and a high performance gradient system (50 mT/m, 200 mT/m/ms), the isotropic resolution is limited to 0.4 mm. However, when this method is instead employed with a dual half-echo 3D radial trajectory, as shown in Figure 2, a larger extent of k -space may be acquired within the TR interval as the half-echoes formed by the dephaser and rephaser are encoded as separate radial lines, with a small tangential pulse to change projection angle in between. For implementation of this new 3D radial FS-ATR technique at 3.0T, TR1 and TR2 were chosen to be 3.45 ms and 1.15ms, respectively. The phase of the second RF pulse is set to be 180°, which when combined with the traditional SSFP 0-180° phase cycle, results in an RF phase cycling scheme of (0, 180, 180, 0, 0, ...) in degrees.

Placement of the stopband in 3D radial LC-SSFP technique requires setting the center frequency at the midpoint of fat and water before sampling k -space twice with the RF phase alternating by π radians each TR in the first pass and remaining constant in the second pass. Linear combinations of these two passes yield water and fat volume images. However, at 3.0T, achieving coherent combination of the water signal between the dual half-echoes within each TR requires a large phase correction due to the off-resonant excitation. When data acquisition is extended within the TR to attain ultra-high resolution, this phase correction can actually refocus the unwanted residual fat signal due to ripple in the LC-SSFP stopband. In contrast, the 3D radial FS-ATR sequence presented here provides fat suppression with a single k -space acquisition that is not dependent upon a phase correction, as water is imaged on-resonance.

Three volunteers were imaged with both the 3D radial FS-ATR and 3D radial LC-SSFP sequences on a 3.0T Discovery MR750 scanner (GE Healthcare, Milwaukee, WI) using an 8 channel phased-array knee coil over a 15cm FOV with a 448 x 448 x 448 image matrix and ± 125 kHz receiver BW in 8 minutes. While the LC-SSFP sequence uses a shorter 3.6 ms TR (compared to the FS-ATR combined 4.6 ms TR), the FS-ATR sequence can sample more unique radial lines (104,000) than LC-SSFP sequence (67,000) as LC-SSFP acquires each line twice. FS-ATR thus supports a theoretically higher alias-free FOV.

RESULTS AND DISCUSSION Comparison of the 0.33 mm isotropic resolution knee joint images, shown in Figure 3 for each sequence, demonstrates the superior performance of the FS-ATR sequence in depicting early cartilage degeneration. The 3D radial FS-ATR sequence exhibits fat suppression comparable with that of the 3D radial LC-SSFP sequence, but has significantly reduced noise-like undersampling artifact due to the increased number of unique projection angles sampled. With this advantage, complete visualization of the articular cartilage surface is possible, further enhancing the ability to appreciate submillimeter cartilage defects.

CONCLUSION Compared to 3D radial LC-SSFP, 3D radial FS-ATR offers enhanced image quality with comparable fat suppression as its single k -space acquisition allows a reduction in undersampling artifact. Furthermore, the ability to image on-resonance avoids the image blurring present in 3D radial LC-SSFP when higher resolution requires longer data acquisition intervals. 3D radial FS-ATR is capable of producing ultra-high resolution useful for longitudinal research studies of cartilage degeneration and simultaneous whole organ assessment. In situations where slightly larger voxels are acceptable, isotropic resolution may be reduced and acquired in a clinically acceptable 5 minute scan time.

REFERENCES 1. Klaers *et al*, MRM *in press*. 2. Leupold *et al*, MRM 2006.

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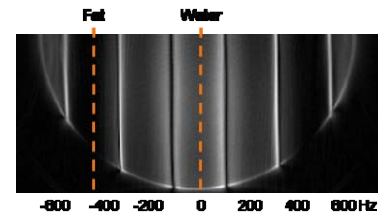


FIGURE 1 3D radial FS-ATR spectral profile with the stopband centered on the fat resonance. Off-resonance was generated with a linear field gradient across the spherical water phantom.

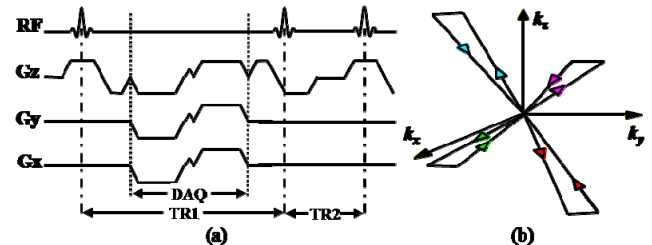


FIGURE 2 Dual half-echo 3D radial FS-ATR pulse sequence (a) and k -space trajectory (b). Two radial lines, each one half of a diameter, are sampled per TR1. Four TR1s are shown.

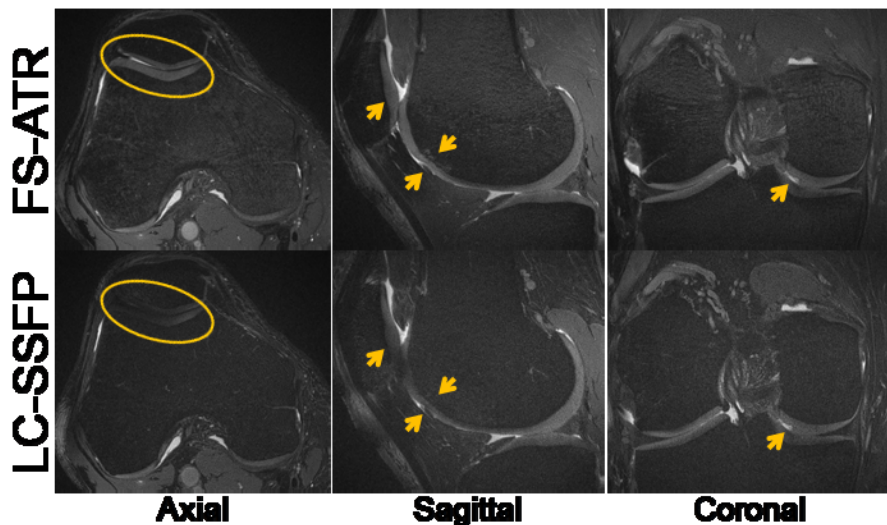


FIGURE 3 0.33 mm in-plane resolution reformats in the axial, sagittal, and coronal planes magnified to show details of the cartilage, bone, and fluid interfaces of the 3D radial FS-ATR and LC-SSFP acquired knee joint. Three slice averaging was performed in each plane for an effective through-plane resolution of 1 mm. FS-ATR consistently shows improved visualization of articular cartilage surfaces and early cartilage defects such as fissures relative to LC-SSFP (arrowheads). Note also the vast reduction in patellofemoral cartilage signal fall-off relative to LC-SSFP (circled).