Extending Performance of Fat-Water Separated Alternating TR SSFP: Ultra-high 0.29 mm Isotropic Resolution

J. L. KLAERS[1], E. K. BRODSKY[1,2], R. KIJOWSKI[2], AND W. F. BLOCK[1,3]

[1]MEDICAL PHYSICS, UNIVERSITY OF WISCONSIN - MADISON, MADISON, WISCONSIN, UNITED STATES, [2]RADIOLOGY, UNIVERSITY OF WISCONSIN - MADISON, MADISON, WISCONSIN, UNITED STATES, [3]BIOMEDICAL ENGINEERING, UNIVERSITY OF WISCONSIN - MADISON, MADISON, WISCONSIN, UNITED STATES

INTRODUCTION The alternating TR (ATR) balanced SSFP technique has proven to be useful for suppression of unwanted species (e.g. fat) while extending the TR interval available for increased spatial resolution [1]. However, even with the use of a high performance gradient system (50 mT/m, 200 mT/m/ms) and ramp sampling, a 3D ATR sequence implemented at 3.0T can only attain 0.4 mm isotropic resolution as its Cartesian trajectory must use half the available acquisition time for prewinding and rewinding the gradients. We have combined the multi-acquisition fat-water separation ATR sequence [2] with a 3D radial trajectory for ultra-high isotropic resolution research studies. We demonstrate 0.29 mm isotropic resolution while providing consistent fat suppression and bright fluid signal in whole joint images of the knee. Excellent depiction of articular cartilage throughout the joint as well as the peripheral vasculature is shown.

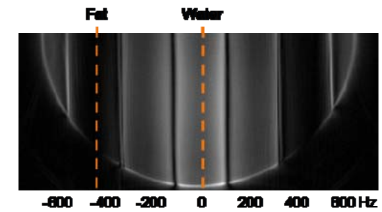

FIGURE 1 Resultant SSFP bands after combination of the in-phase and out-of-phase ATR passes to achieve a water passband and a fat stopband. Off-resonance was generated with a linear field gradient across the spherical water phantom.

METHODS ATR sequences make use of two alternating length TRs along with RF phase cycling to tailor the spectral frequency response. The multi-acquisition ATR sequence acquires the data twice using two different RF phase cycling schemes to obtain in-phase and out-of-phase images which combine to create fat- and water-only images (Fig. 1). Fat-water separation is achieved using a TR2/TR1 ratio of 1/3, with TR1 = 3.45 ms and TR2 = 1.15 ms. Data is only acquired during TR1. The phase of the second RF pulse is 135° in the first pass and 225° in the second, which when combined with traditional 0-180° SSFP phase cycle, results in phase cycling schemes of (0, 135, 180, 225, 0, …) for the first pass and (0, 225, 180, 405, 0, …) for the second pass in degrees. Though the performance of this method generally improves with increased flip angle, the T1/T2 ratio of the object to be imaged should be taken into account. A flip angle of 20° was found to simultaneously image cartilage and vasculature in the knee joint with high signal.

To attain ultra high isotropic spatial resolution, a 3D radial, fully balanced, dual half-echo readout was implemented that completely avoids prewinders and rewinders, as shown in Figure 2. The dephaser and rephaser are encoded as separate radial lines, with a small tangential pulse to change projection angle in between.

Images were acquired on a 3.0T Discovery MR750 scanner (GE Healthcare, Milwaukee, WI) using an 8 channel phased-array extremity coil over a 13cm FOV with a 448 x 448 x 448 image matrix and ±125 kHz receiver BW. Scan time was extended to 10 minutes, a reasonable research scan time, to support the very limited 0.024 mm^3 voxel volume.

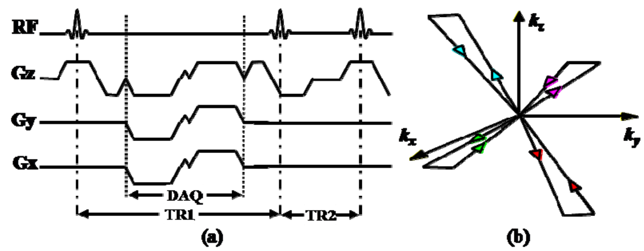

FIGURE 2 Dual half-echo 3D radial ATR pulse sequence (a) and *k*-space trajectory (b) that efficiently uses the available TR1 duration for spatial encoding. Two radial lines, each one half of a diameter, are sampled per TR1. Four TR1s are shown.

RESULTS AND DISCUSSION 0.29 mm isotropic resolution was achieved in the knee joint demonstrating useful applications of the method to cartilage assessment and vasculature imaging. The knee images in Figure 3, reformatted to show axial, sagittal, and coronal views, give excellent high resolution depiction of cartilage with consistent fat suppression over the joint and high cartilage/fluid and cartilage/bone CNR. In Figure 4, the oblique angle MIPs of the knee joint from the same exam demonstrate the utility of this method for high resolution vasculature imaging and may be compared to 3D Cartesian implementations of this method with 1 mm isotropic resolution [2].

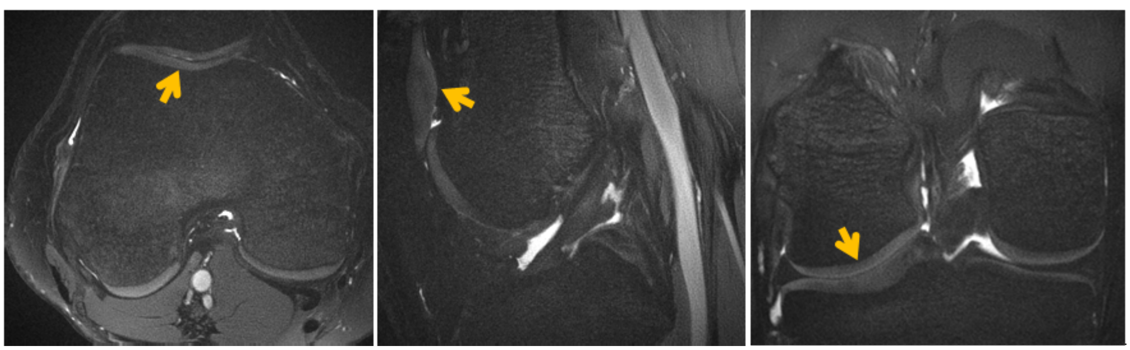

FIGURE 3 0.29 mm isotropic resolution reformats in the axial, sagittal, and coronal planes magnified to show details of the cartilage, bone, and fluid interfaces. Note the fine depiction of the cartilage surfaces and ACL (arrowheads).

The 3D radial trajectory not only makes ultra-high isotropic resolution possible through rapid *k*-space acquisition, it also offers the ability to reformat data from a single scan along any orientation. Slice averaging may be performed in any plane using a varying number of image slices to retrospectively adjust the trade-off between SNR and partial volume artifacts. The same 0.29 mm isotropic resolution presented here may be attained using a larger FOV and an increased receiver bandwidth (±250 kHz). Such an example is not shown due to an implementation limitation in the off-line reconstruction, but will be included in future work.

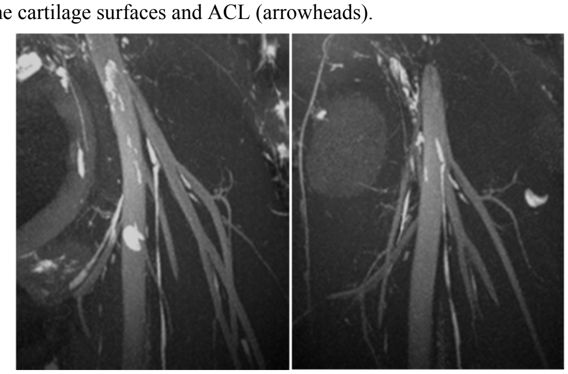

Figure 4 Oblique MIPs of the vasculature in the knee joint acquired in the same 0.29 mm isotropic resolution scan that produced the cartilage images shown in Figure 3.

CONCLUSION The performance of the multi-acquisition fat-water separation ATR SSFP sequence has been extended with the implementation of a 3D radial trajectory. Ultra-high 0.29 mm isotropic resolution is demonstrated in the knee joint with applications in cartilage assessment and vasculature imaging.

REFERENCES 1. Leupold *et al*, MRM 2006. 2. Çukur *et al*, MRM 2008.

ACKNOWLEDGEMENTS Research support provided by NCI R01 CA116380-03, the University of Wisconsin Medical Education and Research Committee grant, and GE Healthcare. The authors would also like to acknowledge Tolga Çukur's helpful conversations.