Multi-Echo IDEAL-GRE Water-Fat Separation for Rapid Assessment of Cartilage Morphology

C. A. Chen[1], C. T. John[2], B. A. Hargreaves[3], S. B. Reeder[4], S. L. Delp[5], R. A. Siston[6], and G. E. Gold[3]

[1]Radiology, Stanford University, Stanford, CA, United States, [2]Computer Science, Stanford University, CA, United States, [3]Radiology, Stanford University, CA, United States, [4]Radiology, University of Wisconsin-Madison, WI, United States, [5]Mechanical Engineering and Bioengineering, Stanford University, CA, United States, [6]Mechanical Engineering, Ohio State University, OH, United States

Introduction: Three-dimensional (3D) MRI is useful to measure articular cartilage volume and thickness. The primary imaging sequence for quantifying cartilage morphology has been 3D spoiled gradient echo with chemical fat saturation (FS-SPGR) or water excitation [1, 2]. Another method of reducing signal from lipid is chemical-shift-induced phase separation, such as Iterative Decomposition of water and fat with Echo Asymmetry and Least squares estimation (IDEAL) [3, 4]. Although IDEAL originally required 3 acquisitions to separate water and fat, scan times can be significantly shortened by using a multi-echo 3D-IDEAL gradient-spoiled echo (GRE) method requiring only 1 acquisition [5, 6]. Multi-echo IDEAL-GRE provides images with bright synovial fluid, which is useful to outline cartilage surface defects [7] and may detect other pathology. We compared cartilage SNR and volume measurements of multi-echo IDEAL-GRE with FS-SPGR in 10 cadaver knees at 1.5T.

Methods: Ten knees (seven fresh-frozen cadavers) were imaged using a GE Signa TwinSpeed 1.5T MRI scanner (GE Healthcare, Waukeska, WI) and an 8-channel knee coil. FS-SPGR was done with TR/TE 15/2 ms, a 25-degree flip angle, bandwidth of $\pm$ 31.25 kHz, one signal average, and fat saturation. Multi-echo IDEAL-GRE used a TR of 15 ms, three echoes with TE of 2.7, 5.4, and 8.4 ms, a 20-degree flip angle, and $\pm$ 83 kHz bandwidth. All scans were 256 x 256, 16 cm field-of-view, 1.5 mm section thickness, 68 sections, and 4:06 in scan time. Flip angles were adjusted to enhance cartilage to fluid contrast. Multi-echo IDEAL-GRE images were reconstructed on-line using the IDEAL algorithm [3]. SNR in each subject was calculated by dividing the average measured signal from 5 regions of interest in the trochlear cartilage by the standard deviation of the noise. SNR values were compared using a Student's t-test. Cartilage volume was measured by segmentation through an image processing software program (3D Slicer, version 2.6; Brigham and Women's Hospital, Cambridge, Mass.), with both combined and water frequency images used in multi-echo IDEAL-GRE segmentation. An experienced observer supervised segmentation. Cartilage volume measured with the 2 sequences was compared using a Student's t-test.

Results: Multi-echo IDEAL-GRE produced images with higher cartilage SNR (52.3 $\pm$ 9.6 vs. 40.0 $\pm$ 9.3) than FS-SPGR, which was statistically significant ($p < 0.0002$). All images had excellent depiction of cartilage (Figure 2). The multi-echo IDEAL-GRE images produced water, fat, and combined images. The multi-echo IDEAL-GRE sequence produced these images in the same scan time as FS-SPGR. Multi-echo IDEAL-GRE yielded statistically equivalent cartilage volumes to FS-SPGR (Figure 1). Average femoral cartilage volumes were 13.1 $\pm$ 3.4 mL for both FS-SPGR and multi-echo IDEAL-GRE, with a p-value of 0.70. Similarly, tibial cartilage volumes were 5.4 $\pm$ 1.6 for FS-SPGR and 5.3 $\pm$ 1.8mL for multi-echo IDEAL-GRE, with a p-value of 0.21. Finally, patellar cartilage volumes were 3.6 $\pm$ 0.9mL for FS-SPGR and 3.5 $\pm$ 1.0mL for multi-echo IDEAL-GRE, with a p-value of 0.22.

Conclusion: Multi-echo IDEAL-GRE provides a fast, SNR efficient method for examining articular cartilage at 1.5T. Because of the lack of a chemically selective radiofrequency pulse and the use of multiple echoes per TR, multi-echo IDEAL-GRE produces higher SNR cartilage images in the same scan time as FS-SPGR. Fat saturation pulses can take up a large percentage of the TR in FS-SPGR, and can also partially saturate water signal. Multi-echo IDEAL-GRE achieves an effective signal averaging of three in one TR by using all 3 echoes efficiently in the water-fat decomposition.

FS-SPGR is also sensitive to both B0 and B1 inhomogeneity, while multi-echo IDEAL-GRE is not. The ability to provide recombined fat and water images that correct for chemical shift may allow assessment of subchondral bone thickness [8]. Multi-echo IDEAL-GRE can be further accelerated using parallel imaging and partial k-space acquisition [9]. Our results indicate that multi-echo IDEAL-GRE is a highly promising technique for imaging articular cartilage thickness and volume that are equivalent to FS-SPGR at 1.5T.

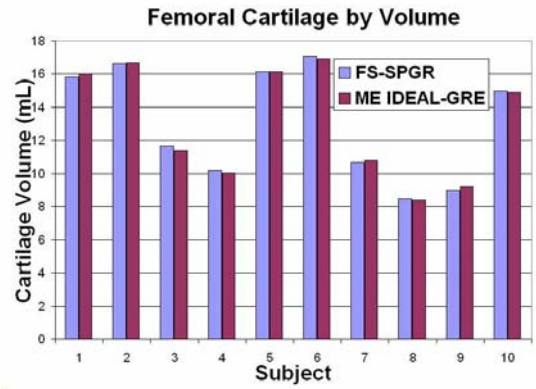

Figure 1: Multi-echo IDEAL-GRE has statistically equivalent cartilage measurements as FS-SPGR ($p>0.20$).

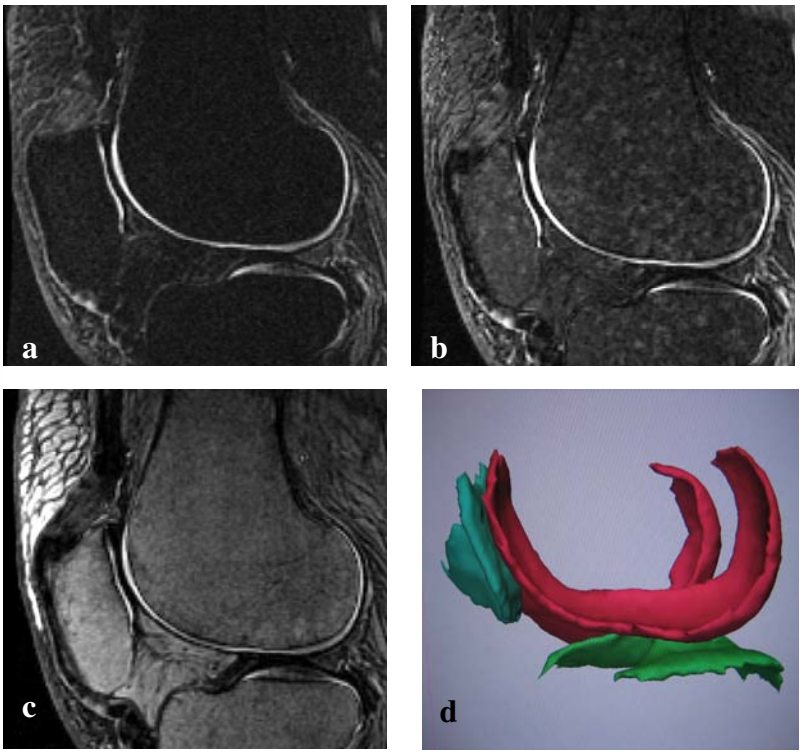

Figure 2: Images from a cadaver. a) FS-SPGR. b) Multi-echo IDEAL-GRE water image. c) Multi-echo IDEAL-GRE combined image. d) Model created from cartilage segmentation of multi-echo IDEAL-GRE water images. Femoral (red), tibial (green), and patellar (blue) cartilage were easily visible from the multi-echo IDEAL-GRE images.

References

[1] Disler, et al. Am J Roentgrnol, 163:887-92 (1994).
[2] Eckstein, et al. Osteoarthritis Cartilage, 10:941-21 (2002).
[3] Yu, et al. MRM. 54(4): 1032-9 (2005).
[4] Reeder, et al. ISMRM 2005, p. 105.
[5] Wieben, et al. ISMRM 2005, p. 2386.
[6] Gold, et al. ISMRM 2006, p. 632.
[7] Mosher, et al. J Magn Reson, 10(2): 178-82.
[8] McGibbon, et al. MAGMA, 16:1-9 (2003).
[9] Siepmann, et al. ISMRM 2006, p. 1251.

Acknowledgements

The authors wish to acknowledge support from NIH grants P41-RR09784, 1R01-EB002524, and 1R01-EB005790.