Optimized Single-Acquisition Lipid- and Water-Selective Imaging at High Field

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Introduction: Strategies for generating separate water- and lipid-selective MR images include the use of spatial-spectral excitation,[1,2] variations on the Dixon method,[3] chemical-shift selective saturation,[4] and magnetization transfer.[5] An advantage of both the spatial-spectral excitation and selective saturation approaches is that water-only or lipid-only images can be obtained in a single acquisition. It is easier to implement spatial-spectral excitation on clinical MR scanners (≤ 3 T) than on high-field imaging systems. Increased B_o produces a larger water/fat frequency shift, $\Delta\nu_{wf}$, which in turn, demands shorter time-increments, τ, between RF and gradient events. Typically, $\tau = 1/(2\cdot\Delta\nu_{wf})$, resulting in $\tau = 2.22$ ms at 1.5T, $\tau = 0.71$ ms at 4.7 T, and $\tau = 0.28$ ms at 11.7 T. Short τ values and the demands of thinner imaging slices mean that gradient slew rates are the main practical impediment to direct implementation on high-field systems of the spatial-spectral pulses developed for clinical MR scanners. Here we describe our experience with implementation of two different strategies for obtaining single-shot lipid- or water-selective images at high field.

Methods: MR experiments were carried out on 4.7 T Varian DirectDrive™ small-animal MRI systems equipped with Magnex high-performance gradients and IEC gradient amplifiers. The imaging systems have gradient slew rates of 0.043 G/cm·μs (t_{rise} = 650μs, G_{max} = 28 G/cm) and 0.215 G/cm·μs (t_{rise} = 270μs, G_{max} = 58 G/cm), respectively. We explored two different strategies for obtaining clean lipid/water separation via single-shot acquisition. The first of these employed side-lobe spatial-spectral excitation (Figure 1); the second used binomial-series frequency-selective excitation 3º-15º-30º-30º-15º-3º plus gradient spoiling appended to the front end of the imaging sequence in order to eliminate the unwanted magnetization isochromat. A variety of different samples, including phantoms and mouse tissue (both *in vivo* and *ex vivo*), were studied. We also explored the benefits of magnetic susceptibility-matching materials (N_2 gas, H_2O, and a water-based surgical lubricant) to overcome artifacts induced by tissue/air interfaces.[6]

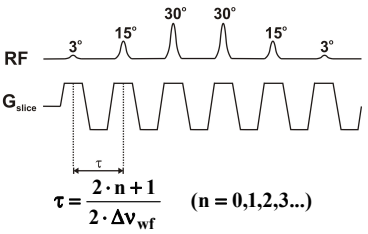

Figure 1. The spatial-spectral excitation pulse developed by Schick uses n = 0.[2] For first side-lobe spatial spectral excitation, n = 1.

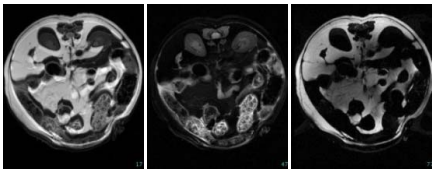

Figure 2. Water+lipid (left) spin-echo, and water-selective (center) and lipid-selective (right) spin-echo images of an obese mouse. Spectral selectivity was achieved with side-lobe

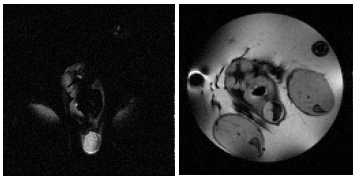

Figure 3. Axial water-selective images of mouse tail and hind limbs acquired with first side-lobe spatial spectral excitation pulses. A susceptibility-matching fluid around the sample (right), essentially eliminates artifacts.

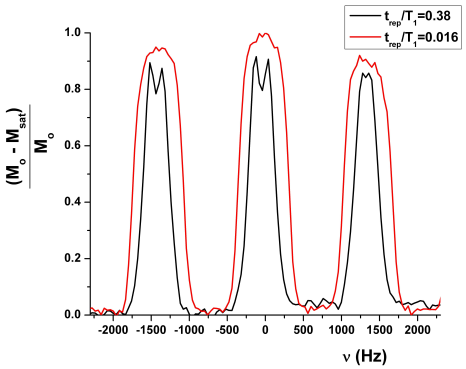

Figure 4. Experimentally-determined frequency-dependent saturation efficacy of the binomial-series frequency-selective excitation plus gradient spoiling. $(M_o-M_{sat})/M_o = 1$ represents perfect saturation. In the case of a multi-slice imaging experiment (red curve), more rapid repetition of the frequency-selective spoiling results in a broader stop-band with a more step-like frequency profile.

Results and Discussion: In cases with the most favorable sample geometry, side-lobe spatial-spectral excitation yields clean separation of water and lipid methylene signals (Figure 2). However, for more complex sample geometries having mismatched magnetic susceptibilities at the surfaces of the tissues of interest (e.g., near lungs, ears and tail), severe artifacts were often observed. Wherever practical, a susceptibility-matching fluid surrounding the tissue of interest largely ameliorates these artifacts (Figure 3). Of the three susceptibility-matching materials we tested, Surgilube (E. Fougera & Co, Melville, NY), a water-based surgical lubricant, offered the best performance characteristics. A specially-designed, inexpensive, mouse holder susceptibility-matching chamber for small-animal work has been developed.

By utilizing the binomial excitation scheme, followed by crusher gradients, one spectral component (water or lipid) can be selectively destroyed prior to the collection of data with a standard imaging sequence. Since the slice-selection gradients are asynchronous with the RF excitation pulse train, the inter-pulse delay time, τ, can be set for n = 0 ($\tau = 0.71$ ms). At 4.7 T, the duration of the six-pulse RF excitation train and a subsequent 3 ms crusher gradient pulse is 6.6 ms. Overall, in the presence of a magnetic susceptibility mismatch, the performance of this technique for selectively imaging one ^{1}H spectral component is far more robust than side-lobe spatial-spectral excitation pulses. The performance advantage is more pronounced for multi-slice acquisitions, where the binomial saturation prior to each slice-selective excitation ensures that the undesired spectral component is driven further toward saturation (Figure 4).

Conclusion: We have demonstrated the ability to collect separate water and lipid MR images using either side-lobe spatial-spectral excitation or a binomial spectrally-selective saturation excitation scheme. For most applications, the saturation strategy is preferred for achieving cleanly separated water- or lipid-only images in a single acquisition. For experiments demanding very short TR (e.g., DCE-MRI studies), the side-lobe spatial-spectral excitation scheme may be preferable, if the susceptibility effects can be managed.

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