Sequence Design Incorporating the LASER Technique for Prostate MRSI at High Field

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INTRODUCTION High field (≥3 T) systems offer a number of advantages for MR spectroscopic imaging (MRSI) of prostate cancer, including improved spectral resolution and increased sensitivity. However, measurement of citrate concentration is complicated by the J-modulation of the citrate resonances at 2.6 ppm. Although a PRESS sequence with frequency selective water/lipid suppression pulses has been widely used at 1.5 T [1] with a TE=130 ms for optimal citrate detection, at 3 T the TE for maximum citrate is approximately 260 ms. This long TE is problematic because of substantial T2 decay. At TE=95 ms the citrate is maximally inverted but this results in quantification issues. Below, we describe our effort to address this problem with pulse-sequences designed to inhibit J-modulation.

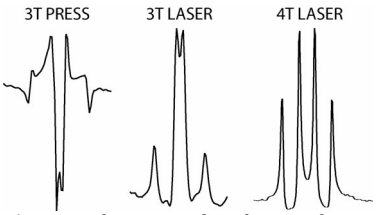

Figure 1: Phantom studies showing the behavior of citrate. With conventional PRESS at 3 T, citrate is inverted with anti-phase sidebands. Using LASER, citrate is upright and the sidebands are in phase. For the 3 T data TE=95 ms and for the 4 T data TE=98 ms.

THEORY A train of closely spaced refocusing pulses can suppress J-modulation, even in strongly coupled systems [2]. This is the main factor contributing to the favorable behavior of citrate when measured using the new sequence, which is adapted from the LASER pulse sequence [3]. With a train of adiabatic refocusing pulses, LASER achieves sharp volume boundaries with insensitivity to errors in flip angle. The latter point is particularly important when a long refocusing train is used, because even small changes in flip angle can cause significant signal loss.

METHODS Phantom studies were performed using conventional LASER on both a GE Signa 3 T and a 4 T with a Varian console. Then, experimental sequence modifications were made to incorporate the water and lipid suppression necessary for prostate MRSI. For suppression, frequency-selective refocusing was chosen instead of one of the pre-pulse schemes, which are sensitive to flip angle and T1 variations and limit the use of spatial-saturation pre-pulse trains. The tradeoff between pulse duration and the width of the passband-stopband transition was a major concern; longer pulse duration gives sharper transitions and more insensitivity to main-field inhomogeneity, but with shorter pulses there is less time for J-modulation to affect citrate. Using the complex-variable implementation of the "Remez exchange" filter design algorithm in MATLAB (The Mathworks Inc. Natick, MA), a dualband filter was designed. This filter was then transformed into the corresponding 180-degree pulse (see Fig. 2) using the inverse Shinnar-Le Roux transform [4]. Following tests in phantoms, in vivo spectra of the human prostate were obtained.

RESULTS The phantom studies using the conventional LASER sequence showed upright citrate even when the echo time was varied over a range of 100 ms. Adding water and lipid suppression at the front-end of LASER required the introduction of an intermediate echo time TE1 (see Fig.2(c)), which allows J-modulation of citrate if it is too long. Based on the results in Fig.3, it seems that water and lipid suppression can be accomplished with a frequency-selective pulse short enough that only minimal modulation occurs.

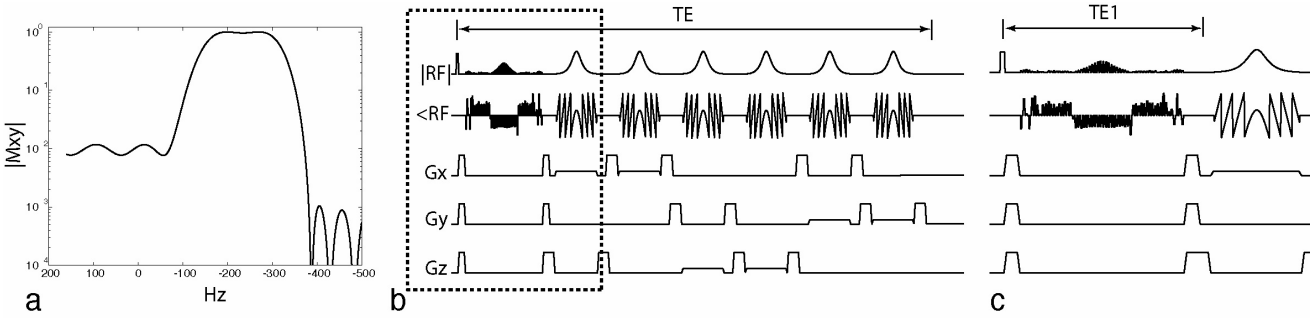

Figure 2: Adaptation of LASER to include water and lipid suppression. A frequency-selective refocusing pulse was designed so that the spin-echo profile (a) accommodates resonances from choline (3.2 ppm) to citrate (2.6 ppm) with a +/-30 Hz tolerance to main-field inhomogeneity. The attenuated passband provides a residual water signal for use as a reference. The full sequence (b) consists of a non-selective 400 us 90-degree pulse, followed by the frequency-selective 180 and a train of six hyperbolic-secant pulses for volume selection. To inhibit J-modulation of citrate, it was crucial to keep the intermediate echo time TE1 (c) as short as possible. The spatial selectivity provided by the refocusing pulses is augmented by outer-volume saturation pulses (not shown) applied before each TR.

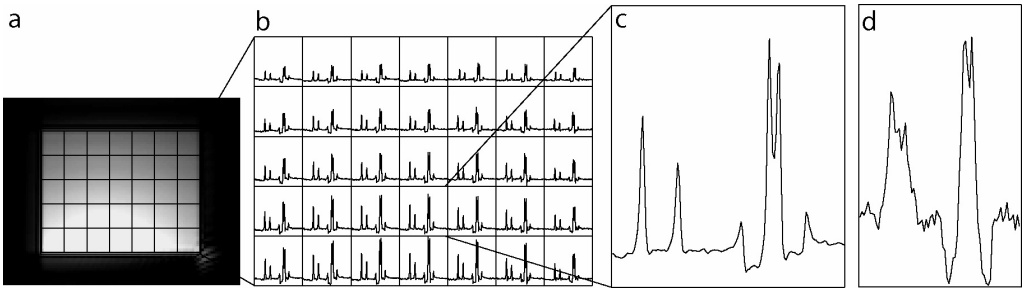

Figure 3: Three-dimensional MRSI using the new pulse sequence (Fig.2). (a) The image of selected volume is shown with the MRSI grid superimposed. (b) Selected spectra from the 3D MRSI array demonstrated upright citrate and good spectra through the selected volume. (c) The spectrum from one 0.15cm^3 voxel showed that citrate is upright with a TE1=17 ms and TE=110 ms. (d) In vivo spectrum acquired from a prostate cancer patient using the band-selective LASER sequence.

CONCLUSIONS This study demonstrates the feasibility in phantoms and in vivo of acquiring citrate spectra immune to J-modulation effects by employing the LASER train of spatially-selective adiabatic refocusing pulses. In order to obtain robust water and lipid suppression for patient studies, a dual-band frequency-selective refocusing pulse was added to partially refocus the water resonance (20 dB suppression) while excluding lipid resonance (30 dB suppression). Initial patient spectra demonstrated the ability of this technique to obtain in vivo MRSI from the human prostate without citrate J-modulation effects.

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