LASER ^{1}H-MRS Optimized For Prostate Spectroscopy with Low B1

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Introduction: Poor homogeneity of excitation RF fields can be a serious problem for localized ^{1}H-MR spectroscopy with PRESS or STEAM sequences. Localized Adiabatic SElective Refocusing (LASER) is sequence with an Adiabatic Half Passage pulse (AHP) for excitation and six Adiabatic Full Passage (AFP) for volume selective refocusing (1) thus, this sequence is ideal for use with non-homogeneous excitation coils. However, the application of this sequence for clinical MR research on humans is often hindered by limited RF field strength or excessive RF power deposition (high Specific Absorption Rates, SAR). The LASER sequence has been modified to incorporate FOCI pulses, which are claimed to reduce peak B1and decrease the chemical shift voxel offset (2). Still RF field requirements and minimum TR remain a problem. Numerically optimization of the modulation (NOM) (3)of the AFP pulses may reduce the B1 threshold for this sequence to a point where it could be used with body coil excitation in a clinical 3T scanner at TR ≤ 2s within the SAR limits set by the FDA. This is particularly useful for ^{1}H-MRS of the prostate because

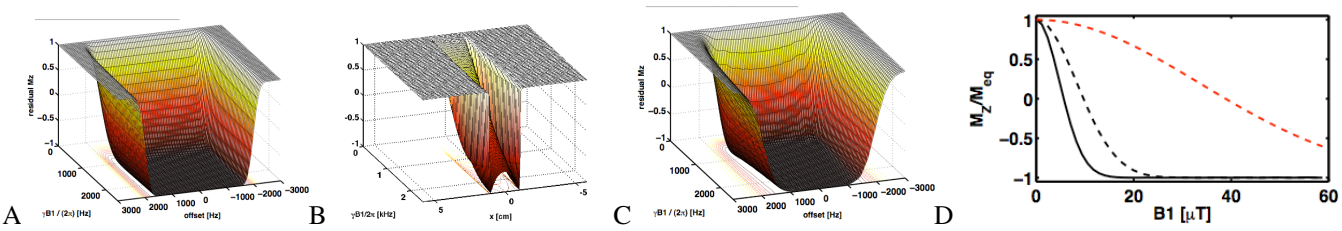

***Figure 1**. Response of 7.5ms AFP pulses as a function of offset and B1. A) HS pulse BW 4kHz B) FOCI pulse based on the HS pulse, FOCI factor 10. Profile shown as spatial response (FOCI pulses work with time varying gradients). C) NOM pulse BW 4kHz as used in the LASEROP sequence. D) On-resonance/mid slice responses of the pulses. Dashed red: FOCI; Dashed black: HS; Solid black: NOM. Note the lower threshold in B1 for the NOM pulse and the high B1 threshold for the FOCI pulse.*

uniquely the LASER sequence produces easily quantifiable in-phase spectra of the strongly coupled AB system of citrate. Accurate quantification of citrate is of vital importance because the signal ratios of choline to citrate are typically used to differentiate benign from malignant prostate lesions. With other sequences, such as STEAM or PRESS, the appearance of the citrate spectrum varies strongly with the sequence timings, often necessitating longer TEs, leading to losses in all other metabolites signals. Moreover, the chemical shift difference and J coupling of citrate resonance depends on pH, concentrations of K^+, Na^+, Ca^{2+}, Mg^{2+} Zn^{2+} and the concentration of citrate itself (4). This leads to additional uncertainty in signal quantification because at least some of these factors are bound to be different in diseased prostates.

Simulations: We tested a hyperbolic secant AFP pulse (HS), a FOCI pulse and a NOM pulse, designed to lower the B1 threshold (Figure 1). The NOM pulse was subsequently tested in a simulation of the LASEROP sequence with a 1D array of spatial offsets and all gradients defining the same region in that dimension. This setup is much quicker than a full 3D simulation, thus allowing the tests with various phase cycle schemes (Figure 2).

Phantom measurements: On a Siemens Trio 3T scanner (Siemens Erlangen, Germany) the LASEROP sequence was tested with 2x2x6 cm voxels placed in a 0.5l phantom containing 90mM citrate, 9mM choline, 12mM creatine. The threshold RF field for the LASEROP sequence was determined by varying the voltage for the excitation pulse and for the first pair of refocusing pulses (Figure 3).

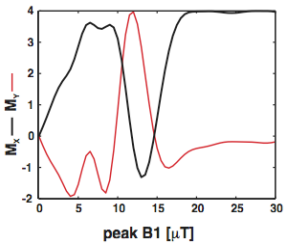

***Figure 2** Simulated mid slice M_X (-),My(-) response of LASEROP after four step phase cycle steps. AHP 3.5 ms, AFP 6.5ms, 4kHz BW TE39ms.*

Results: Both simulations and actual response on the scanner show a threshold of about 20 μT. After four phase-cycled averages in simulation the simulated M_X response is very close to the maximum possible value of four (Figure 2). Spectra obtained with a 21 μT peak RF field for all pulses showed about a 25 % increase in central citrate peak intensities over the best spectra obtainable with PRESS from the same voxel (with echo times optimized, TE1/TE2 48/81ms for this phantom). The bandwidths of the AFP pulses were 3.5-4.25kHz at 6 to 7.5 ms duration. This yielded TE of 39-45 ms with less than 5% unidirectional chemical shift voxel displacement over 3ppm at 3T. This is more than one would get with FOCI pulses (2), but we could not get the threshold of the FOCI pulses low enough to be practical. The LASEROP sequence could be run with a loaded body coil using RF voltages for all AFP and AHP pulses about equal to that needed for a 1ms 180º hard pulse.

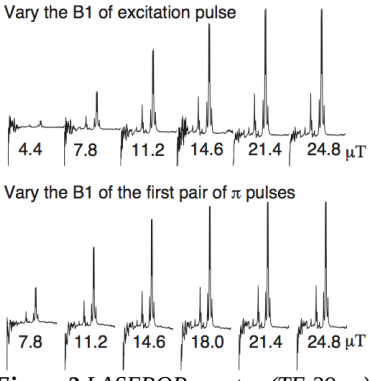

***Figure 3** LASEROP spectra (TE 39ms) of a phantom with citrate, choline and creatine collected with four averages from a 2x2x6cm voxel. The RF amplifier voltage of the AHP pulse (top) and first AFP pulse pair was varied to yield the B1 values indicated (other pulses at 25⌈T).*

Conclusion: Optimized refocusing pulses for use at low B1 makes it possible to use this sequence with more efficient TRs of about 2s with enough slice selection bandwidth to limit chemical shift voxel displacements at 3T to within 4-5%. Thus we now have a sequence that can be used for in-vivo prostate studies on human subjects with body coil excitation and within FDA limitations for SAR and reasonable scan times.

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