Optimal timing for in vivo 1H-MR spectroscopic imaging of the human prostate at 3T

T. Scheenen[1], G. Gambarota[1], E. Weiland[2,3], D. Klomp[1], J. Fütterer[1], J. Barentsz[1], A. Heerschap[1]

[1]Radiology (430), University Medical Center Nijmegen, Nijmegen, Netherlands, [2]Siemens Medical Solutions, Erlangen, Germany, [3]University of Bremen, Bremen, Germany

Introduction

In the continuing search for a non-invasive imaging technique that can reliably differentiate prostate cancer from benign prostatic hyperplasia and healthy tissue, proton MR spectroscopic imaging (MRSI) of the human prostate is of prime interest, since prostate cancer tissue is characterized by reduced levels of citrate and increased levels of choline (1-2), which both are detectable *in vivo* with ^{1}H-MRSI. Increasing the magnetic field strength from 1.5T to 3T may have substantial benefits for prostate MR, therefore we assessed the optimal timing for ^{1}H-MRSI of the prostate at 3T. For this purpose we simulated the spectral shape of the citrate methylene protons with density matrix calculations and compared the theoretical spectra with in vitro measurements of a phantom containing a solution of citrate, creatine and choline. With different values for the pulse timing and repetition time, the prostates of 10 patients with prostate cancer were measured *in vivo* to estimate T_1 and T_2 relaxation times of the relevant metabolites at 3T. These findings were combined to compare MRSI at 3T with MRSI at 1.5T and to describe an optimal pulse sequence timing for 3D ^{1}H-MRSI of the prostate at 3T.

Materials and methods

Based on the density matrix formalism (3-4) to predict the spin dynamics of strongly coupled spin systems we simulated the spectral shape of the citrate signal at 3T as a function of pulse timing and compared it with single voxel PRESS measurements of a phantom containing citrate. The pulse timing of the PRESS sequence is defined as $90_x - \tau_1 - 180_y - \tau_2 - 180_z - (\tau_2 - \tau_1)$ echo. Three selected spectral shapes were used to measure the citrate signal in vivo and to calculate T2 values. After informed consent was obtained, 10 patients with biopsy-proven prostat cancer were measured on a 3T MAGNETOM Trio whole body scanner (Siemens Medical Solutions, Erlangen, Germany) with an endorectal surface coil (Medrad Inc., Indianola, PA, USA). After acquiring high-resolution multislice T2 weighted turbo spin echo images in three directions for an anatomical overview of the prostate and surrounding tissues (5600/109 ms [TR/TE], 512x256 matrix and 180x90mm FOV, scan time 3 min 15 s, 15 slices with thickness 4 mm) we used acquisition weighted 2D ^{1}H-MRSI -with outer volume saturation and dual frequency selective refocusing pulses to suppress water and lipid signals- to acquire spectra at three different echo (75, 100 and 145 ms) and repetition times (600, 1200 and 2000 ms) (other parameters: FOV 140x117 mm, matrix size 12x10, slice thickness 10 mm, acquisition bandwidth 1250 Hz, 512 spectral data points, 3 weighted averages, measurement time from 1 to 3 minutes). After filtering and zerofilling the spatial dimensions the spectra were analyzed with the PRISMA software package, that performs a time domain fit to the spectral information, using model functions for the different metabolites at different pulse timing as prior knowledge. The resulting signal integrals for citrate (taking into account the modulation of the signal as a function of pulse timing) and choline were fitted to mono-exponential equations to estimate both T1 and T2 relaxation times.

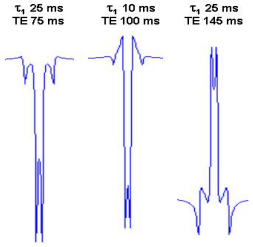

Figure 1. Three selected simulated spectral shapes of citrate at 3T

Results and discussion

The simulated integral of the citrate spectrum varies dramatically with pulse timing, and corresponds to in vitro measurements of citrate. We found three combinations of the PRESS pulse timing, that on one hand could still accommodate dual-frequency selective refocusing pulses to suppress water and lipid signals, and on the other hand produced an echo at a reasonably short echo time with a spectral shape that had two large absorptive inner lines and two small outer lines (Fig.1). At TE 75 and 100 ms the inner lines are 180 degrees out of phase. In vivo measurements showed a similar spectral shape of citrate (Fig.2), and, apart from citrate, signal intensity from ~2.9 to 3.3 ppm including creatine, choline and possibly polyamines. Residual lipid signals below 2.5 ppm decreased with increasing echo time. Calculations of the relaxation times after fitting the individual spectra resulted in the following values: $T_{1,citrate}$ 0.47 ± 0.14 s, $T_{2,citrate}$ 0.17 ± 0.05 s, $T_{1,choline}$ 1.6 ± 0.5 s, $T_{2,choline}$ 0.24 ± 0.09 s. Using these values for 3T and literature values (5) for relaxation times at 1.5T we calculated the relative signal to noise ratio (SNR) per unit time for citrate and choline at 1.5 and 3T (table 1), assuming a linear increase in SNR with B_0 and incorporating the modulation of citrate with pulse timing. It is clear from this table that apart from a possible increase in spectral resolution, the increase in SNR when moving from 1.5 to 3T can be dramatic.

Conclusions

Theoretically simulated shapes of the citrate spectrum at 3T corresponded with actual in vitro and *in vivo* measurements of the citrate signal. With this validation three combinations of pulse timing with an optimal spectral shape were selected to calculate T_1 and T_2 relaxation times of citrate and choline at 3T. With these calculated values in the *in vivo* prostate at 3T we can conclude that both the echo time and repetition time in MRSI of the prostate at 3T need to be short (75 ms and 750 ms respectively) for an optimal SNR per unit time of the experiment, greatly exceeding the attainable SNR per unit time at 1.5T.

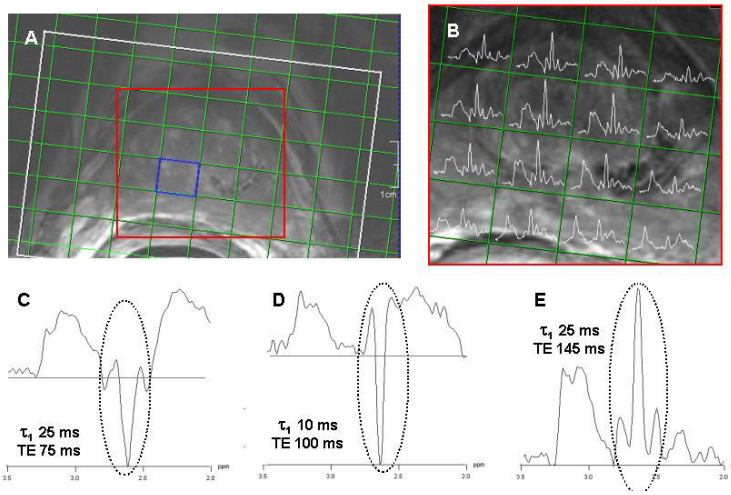

Figure 2. 2D ^{1}H-MRSI examination of the prostate of a patient. (a) is a T_2-weighted TSE image of the prostate on which the MRSI matrix is overlaid. The white box indicates the PRESS-selection box, the red box is enlarged in (b), in which for every voxel the spectrum is shown from 2.0 to 3.5 ppm at an echo time of 145 ms. The blue voxel in (a) is the location of the spectra in (c) to (e).

Table 1. The SNR per unit time for citrate and choline in the *in vivo* prostate at 1.5 and 3T

	1.5 T		3 T			
	TE 120 ms, TR 1.5 s	TE 120 ms, TR 0.65 s	TE 75 ms, TR 1.5 s	TE 75 ms, TR 0.75 s	TE 145 ms, TR 1.5 s	TE 145 ms, TR 0.75 s
Citrate	0.26	0.34	0.85	0.99	0.22	0.26
Choline	0.40	0.40	0.73	0.63	0.54	0.47

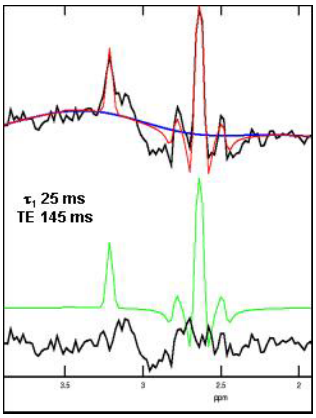

Figure 3. Spectral fit with PRISMA. From top to bottom: measured spectrum (black) overlaid with the fit (red) and baseline (blue), metabolite fit (green), residual between data and fit (black).

References:

1. Kurhanewicz J *et al.* Urology 1995;45:459-466.
2. Heerschap A *et al.* Anticancer Res 1997;17:1455-1460.
3. Mulkern RV and Bowers JL. Concepts Magn Reson 1994;6:1-23.
4. Stables LA *et al.* J Magn Reson 1999;140:305-314.
5. Heerschap A *et al.* Magn Reson Med 1997;37:204-213.