^{31}P MR spectroscopic imaging with nuclear Overhauser enhancement at 7T in the human prostate

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Introduction - At a field strength of 7T, the increased spectral resolution of ^{31}P enables detection of the separate resonances of phosphocholine (PC) and phosphoethanolamine (PE) in the human prostate [1]. The levels of these metabolites, together with those of glycerophosphocholine (GPC) and glycerophosphoethanolamine (GPE), may be helpful in prostate cancer characterization [2]. To achieve 3D ^{31}P MRSI with relevant spatial resolution in a clinically acceptable measurement time, the repetition time of the sequence should be optimized and possible signal enhancement strategies should be employed. In this study we assessed T_1 relaxation times of ^{31}P metabolites in the human prostate and evaluated the effect of nuclear Overhauser enhancement (NOE) on ^{31}P MRSI detection sensitivity at 7T.

Methods - Two healthy volunteers (32y and 37y) were measured on a 7T whole body MR system (Magnetom 7T, Siemens, Erlangen). A ^{31}P T_X/R_X endorectal coil tuned to 120.3 MHz was used in combination with a ^{1}H T_X/R_X 8-channel body array coil [3]. 3D phasemap shimming was used to optimize the B_0 homogeneity in the prostate. A B_1^+-phase shimming algorithm was employed to maximize ^{1}H phase coherence in the prostate to allow efficient continuous wave irradiation for NOE. Transversal T_2-weighted fast spin echo images (TR=3s, TE=71ms) were recorded to provide an anatomical background for 3D ^{31}P spectroscopic imaging. For T_1 measurements (N=1) a progressive saturation ^{31}P MRSI sequence with a 5.12 ms adiabatic tanh12 90° pulse (γB_1=670Hz) was used with TRs that ranged from 300ms to 2.3s (nominal voxel size: 20x20x20mm^3). In the other volunteer 3D ^{31}P MRSI with 8ms BIR-4 45° RF pulses (γB_1=960Hz) was performed twice, with a nominal voxel size of 12.5x12.5x12.5mm^3 (TR=1500ms, TA=11.4 minutes). In the second scan the proton spins of water were saturated during the 1.5s TR (except during 204ms signal acquisition) using low-power continuous wave irradiation (γB_1=20Hz) to assess the NOE. All measurements were performed within SAR safety limits. Fitted peak integrals were used for quantification of the measurements.

Results and discussion – The metabolites of which a reliable fit could be obtained in the consecutive measurements of the progressive saturation experiment were used to calculate T_1 values (table 1 and fig. 1). GPC and GPE signals were very low or not present in the prostate spectra, even with NOE (fig. 2). Since two peaks resonated with some overlap in the chemical shift range of inorganic phosphate (Pi) these could not be reliably fitted. The T_1 relaxation times of phosphocreatine (PCr) and γATP in prostate at 7T as obtained in this study were comparable to those reported for human brain at the same field strength [4]. Another 7T study reported longer γATP T_1 times in human muscle, but also a comparable PCr T_1 time [5]. The measured T_1 of PE in prostate was slightly shorter than in human brain. No separate T_1 values for PC at 7T have been reported before. The Ernst angle for the calculated T_1 values of PE and PC at a TR of 1500 ms were 51.5° and 40.1°, hence the choice of an adiabatic excitation flip angle of 45°. The signal-to-noise of PC at this TR was still good, as can be seen in fig. 2. Compared to reported numbers for prostate at 1.5T [6], all measured ^{31}P T_1 times were increased at 7T. The differences in T_1 relaxation times between the left and right muscle surrounding the prostate may result from B_0 inhomogeneity differences outside the prostate, leading to less accurate fitting of the peak integrals. The low signal intensities of GPC and GPE were in accordance with in vitro measurements of normal prostate tissue [7] and benign prostate tissue [2], however in the latter study even smaller PC concentrations were reported.
Well-resolved spectra were obtained throughout the prostate and surrounding tissue with the TR=1.5s ^{31}P MRSI sequence with and without NOE (fig. 2 and 3). In the metabolite map of the PE/PCr ratio in fig. 4 the differences between prostate and surrounding tissue are clearly visible. A positive NOE effect was observed for PE, PC and PCr in the prostate (table 1, fig. 2). This is in line with previously published NOE data from ^{31}P metabolites in brain at 7T [4]. Since both metabolites of interest for studying prostate cancer, e.g. PE and PC, benefit from NOE, it might be possible to increase the MRSI resolution without changing the total acquisition time. This has to be investigated in patients. Also other signal enhancement techniques, e.g. polarization transfer, should be explored to increase signal intensity.

	PE	PC	PCr	γATP
T_1 prostate (s)	3.16 ± 0.86 *	5.59 ± 2.67 *	3.51 ± 0.54	1.27 ± 0.10
T_1 smooth muscle (s)	-	-	R: 2.09 ± 0.22 L: 2.4 ± 0.18	R: 0.97 ± 0.15 L: 1.51 ± 0.35
NOE prostate (%)	38 ± 7	22 ± 28	18 ± 10	-0.2 ± 7

*Table 1: Apparent T_1 (s) and NOE (%) of ^{31}P metabolites in prostate and surrounding muscle tissue at 7T. *: no signal at TR=300ms.*

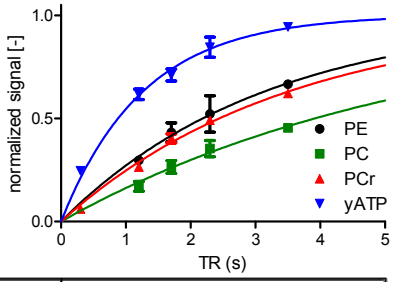
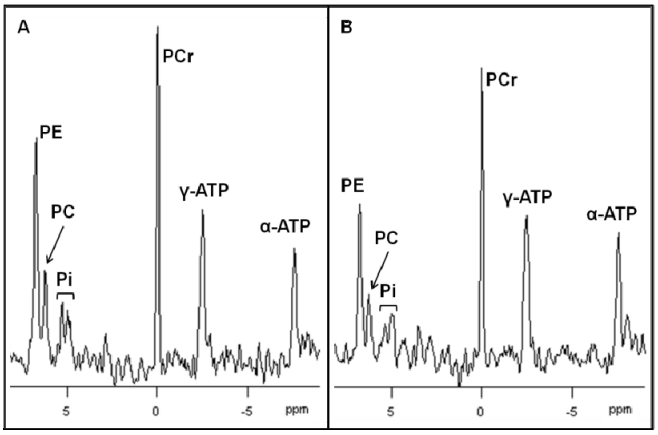


Fig. 1: T_1 recovery curves of ^{31}P metabolites in prostate.

Fig. 2: ^{31}P spectra (TR-1.5s, TA=11.40min) of the human prostate with NOE (A) and without NOE (B).



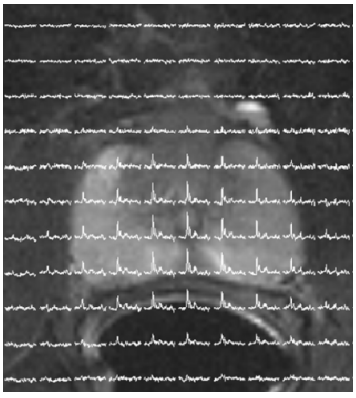


Fig. 3: ^{31}P spectral map (2-8.5ppm) with NOE of the prostate midgland on top of a T2W-image at 7T (volunteer 2).

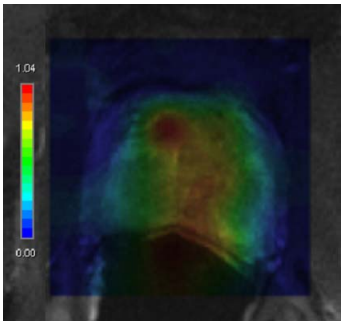


Fig. 4: Metabolite map of PE/PCr ratio from ^{31}P MRSI in prostate midgland on top a T2W-image at 7T (volunteer 1).

Conclusion – T_1 relaxation times for ^{31}P at 7T were measured in the healthy human prostate. By choosing an appropriate TR of 1500ms in combination with an adiabatic excitation pulse of 45˚ and irradiating the water resonance to obtain a positive NOE effect, ^{31}P MRSI of the prostate is possible with a relevant spatial resolution in a clinically acceptable measurement time.

References [1] Kobus et al, ISMRM (2011), abstract 3057 [2] Swanson et al, MRM 60:33-40(2008) [3] Orzada et al, ISMRM (2009), abstract 2999 [4] Lei et al, MRM 49:199-205(2003) [5] Bogner et al, MRM 62:574-582(2009) [6] Thomas et al, JMR 99:377-386(1992) [7] Cornel et al. J Urol. 150(6):2019-2024(1993)
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