Improvements of RF field Transmission and Detection Sensitivity for 31P MRS with Ultra High Dielectric Constant (uHDC) Material at 7.0 T

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Target Audience: MR spectroscopy scientists with focus on X-nuclei; RF engineers interested in utilizing ultra-high dielectric constant (uHDC) materials

Introduction: It has been shown that materials with ultra high dielectric constant (uHDC) can significantly improve B_1^+, B_1^- and SNR while drastically reducing transmit power at 3T. At 7T the resonance frequency of ^{31}P spin is 120.6 MHz. similar to that of proton (^{1}H) at 3T where uHDC ceramics have successfully shown to lead to great improvements. In this study we explored the feasibility of improvement for ^{31}P MRS at 7T.

Based on computer simulation, the optimal permittivity for ^{1}H MRI is 1,000 (uHDC) for 125 MHz of RF operation frequency at 3T, and between 150 and 300 for 300 MHz at 7T. Since the resonance frequency of ^{1}H at 3T is similar to that of ^{31}P at 7T, we anticipated that *in vivo* X-nuclei *MRS* will benefit substantially from the common availability of high-field MR scanners and the uHDC technique, and partially overcome the limitations of high specific absorption rate (SAR) and low signal-to-noise ratio (SNR), potentially for many human applications.

Materials and Methods: As shown in Fig. 1, the RF coil consisted of a 80 mm-diameter single-loop ^{1}H surface coil for anatomic imaging and B_0 shimming, and a 130 mm-diameter single-loop ^{31}P coil with reasonable decoupling between the two coils. The ^{31}P coil circled around a monolithic block of lead zirconium titanate (PZT) material (TRS, State College, PA, USA). For both coils, the transmit efficiency ($|B_1^+|$) and receive sensitivity ($|B_1^-|$) were calculated under with and without uHDC conditions using xFDTD (Remcom, State College, PA, USA). The ATP phantom was a 150 mm-diameter spherical container filled with 2 liter 20 mM ATP, 40 mM NaCl, and 10 mM $MgCl_2$ at pH 7.0. All NMR measurements were conducted at 7.0 T / 900 mm bore human scanner (Siemens). A 3D ^{31}P chemical shift imaging (CSI) with Fourier Series Window (FSW) technique [1] was collected (TR=2 s, spectral bandwidth = 5000 Hz, FOV = 140x140x100 mm^3, and hard excitation pulse = 300 us) with and without uHDC block under the optimal tuning and matching conditions. The nominal voxel size in 3D CSI was approximate 8 ml, and total acquisition time was 15min. The RF pulse power was optimized for the voxel of interest using double-angle B_1 mapping technique [2]. For the optimized condition, all data were acquired from the same voxel position and same coil load condition. Post-processing included zero-filling the FIDs to 32k data points, and applying 10 Hz line-broadening. Signal-to-noise (SNR) calculated using the ATP peak of the ^{13}P spectra and standard deviation of the noise.

Results and Discussion: As shown in Fig. 2, both $|B_1^+|$ and $|B_1^-|$ are greatly enhanced. The B_1 enhancements well correlated with the SNR improvement in the CSI spectra as shown in Fig. 3. Even in the center of the phantom both fields are at least 40% improved. The SNR of the ^{31}P spectrum shown in the optimized voxel was improved by 138 % with the uHDC block. Such SNR improvement is accompanied by an at least 43 % reduction of RF-power for acquiring the spectra as summarized in Table 1. In our experiment, great care was taken to control the potential confounds such as Bo shimming, RF power calibration, sample position and coil tuning and matching.

Conclusion: We demonstrated that uHDC materials significantly improved ^{31}P spectroscopy sensitivity at 7T. The translation from ^{1}H imaging at 3T to ^{31}P spectroscopy at 7T opened up an avenue for improving X-nuclear (^{17}O, ^{23}Na etc.) MRS in human at high field in which SNR remains a major challenge due to extremely cellular metabolites of interest.

Acknowledgement: NIH RO1 grants: NS057560, NS070839; S10RR026783 & P41 EB015894.

References: [1] Garwood *et al.*, *JMR* **75**:244-261 (1987); [2] Insko *et al.*, *JMR Ser A* **103**: 82-85 (1993).

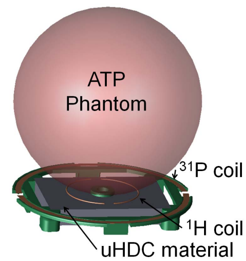

Figure 1 Experimental setup including Proton-coil (D=80 mm) and Phosphorous-coil (D=130 mm) as well as the ATP-phantom (D=150 mm) and the uHDC block (102 mm x 77 mm x 14 mm).

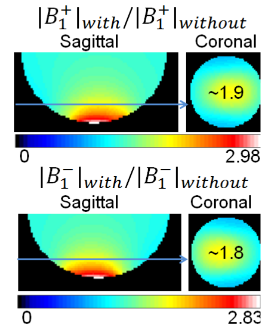

Figure 2. The ratio images of ^{31}P coil B_1 fields with and without uHDC block. B_1 fields were at least 80 % higher than that without uHDC in the ROI with 20 mm depth into the phantom.

Table 1 Summary of results

	w uHDC	w/o uHDC	change [%]
Reference voltage [V]	51.87	69.2	- 25.0
Reference power [W]	53.8	95.77	- 43.0
Max signal [AU]	27.39	18.61	+ 47.2
Noise [AU]	0.092	0.145	- 36.5
SNR	297	124.8	+ 137.9

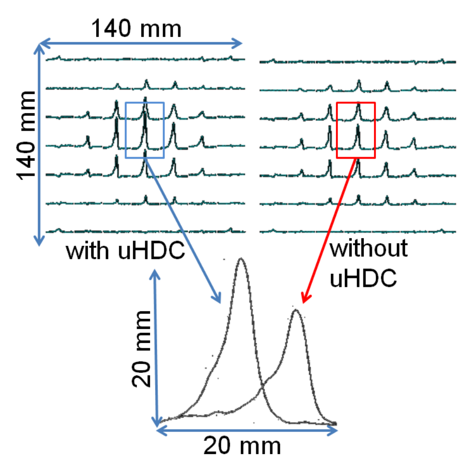

Figure 3 Comparison of ^{31}P Chemical shift imaging spectra from the ATP phantom obtained with and without uHDC block.