Adiabatic Multi Echo Spectroscopic ImagiNG (AMESING) for boosted 31P sensitivity at 7 Tesla

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Introduction: Phosphorus MR spectroscopy is hampered by an intrinsic low sensitivity. SNR in ^{31}P MRS is further impeded by long longitudinal relaxation times. In addition, especially at higher fields, susceptibility effects may be strong, which will reduce T_2*. However, the T_2 of many ^{31}P metabolites is an orderof magnitude larger, therefore SNR can be significantly increased using multi-echo sequences. Here we implemented an Adiabatic Multi Echo Spectroscopic ImagiNG (AMESING) sequence with spherical k-space sampling (figure 1) on a whole body 7 Tesla MR system (Philips, Cleveland, USA). Spatial encoding is done using compensated phase encoding gradients, i.e. the echoes are not used for speeding up k-space sampling but for averaging and thus even enabling T_2 measurements of ^{31}P metabolites. The BIR-4 180 pulses are surrounded by spoiler gradients that vary in gradient strength with the shot number n. Here we demonstrate the validation of the sequence on the human calf muscle and the boosted SNR in the detection of low concentrated ^{31}P metabolites in the human breast.

Experimental: The AMESING sequence was applied to the calf muscle of a healthy male volunteer and the breast of a female volunteer using 8x8x8 voxels of 20x20x20 mm^3, TR = 6 s,TE = 45 ms, acquiring 1 FID and 5 echoes in one TR with a total scan time of 25:36 minutes per subject. Details about the adiabatic pulses can be found in [1]. Acquired data was spatially Hamming filtered (effective voxel size 39 ml), and apodized and 2x zerofilled in time domain. The FID spectra were phased (0th and 1st order) and the baseline corrected, the echo spectra were only 0th order phased. SNR weighted averaged sum spectra for the different ^{31}P metabolites of the calf muscle were calculated. The noise in the SNR calculations was based on FID spectra without linear phasing and baseline correction. Additionally, the signal intensity (baseline corrected) for all detected ^{31}P metabolites was calculated from the absolute echoes and from the absolute FID signal and plotted as a function of the echo time for a voxel in the calf muscle and a voxel with glandular tissue in the breast to calculate their T_2.

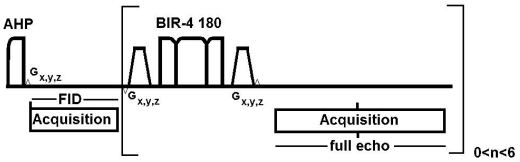
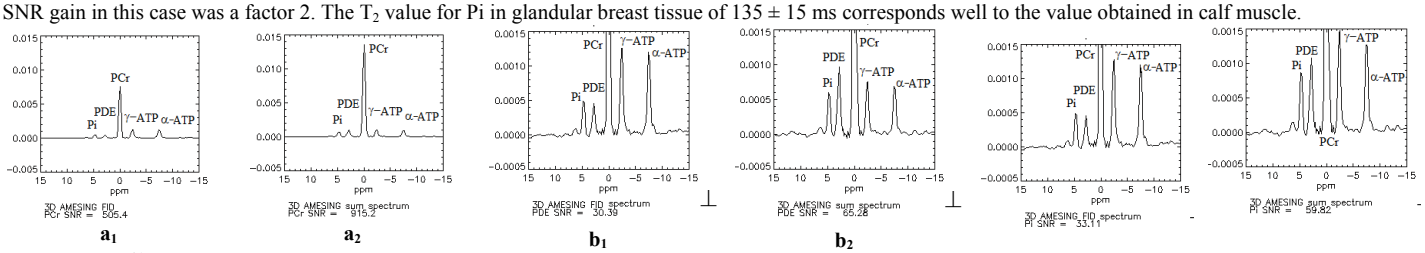


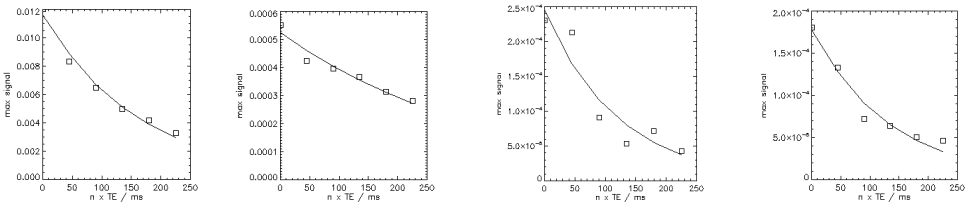
Fig. 1. Adiabatic Multi-Echo Spectroscopic ImagING (AMESING) sequence used for ^{31}P MR spectroscopy.

Results and discussion: Figure 2a-c show the FID and the SNR weighted averaged ^{31}P MR spectra, acquired from a calf muscle voxel. Absolute signal decay as a function of the number of echo times are shown for calf muscle PCr, PDE, and Pi in figure 3a-c. The T_2 values for PCr, PDE, and Pi, derived from the data in Fig. 3a-c are 164 ± 10 ms, 346 ± 40 ms, and 120 ± 28 ms respectively. These values correspond well to published values that were averaged over 7 subjects, 217 ± 14, 314 ± 35, and 109 ± 17, and acquired in a larger volume (112-169 ml) at 7T by Bogner et al. [2]. Our values are acquired from a single subject and derived from a ~ 39 ml sample. The SNR weighted average spectrum depicted in Fig. 2a$_2$ has an SNR that is 1.8 times larger than the SNR of the FID spectrum that was acquired as the first shot of the sequence. For PDE the increase in SNR is, due to the longer T_2, even a factor 2.1, see Fig 2b$_2$. Figure 4a shows the data acquired for a voxel with chest wall muscle and a voxel with glandular breast tissue. In the present case, only Pi and PDE could be clearly detected in the glandular tissue. The SNR gain in this case was a factor 2. The T_2 value for Pi in glandular breast tissue of 135 ± 15 ms corresponds well to the value obtained in calf muscle.



a$_1$ **a$_2$** **b$_1$** **b$_2$**

Fig. 2a-c. FID ^{31}P MR spectra (**a$_1$**, **b$_1$**, **c$_1$**) and corresponding SNR weighted averaged spectra (**a$_2$** PCr-weighted; **b$_2$**, PDE-weighted; **c$_2$** Pi-weighted) for calf muscle.

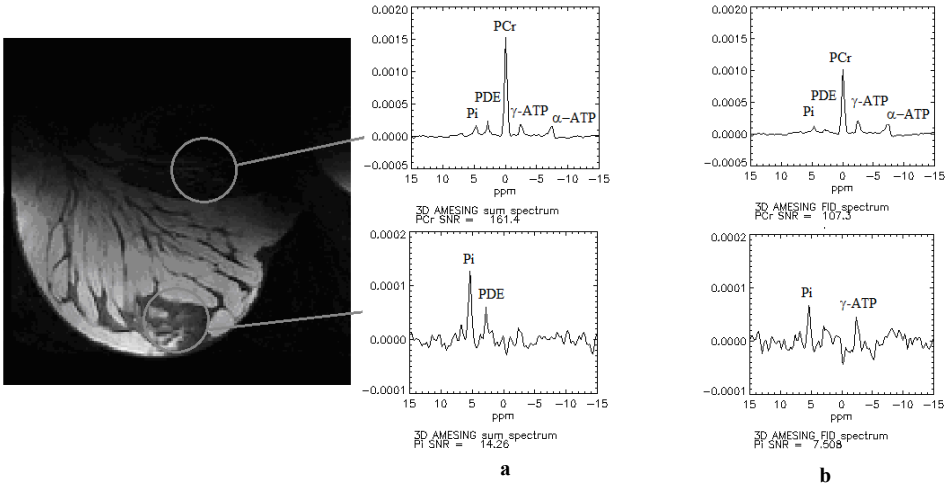


a **b** **c$_1$** **c$_2$**

Fig. 3. ^{31}P MR Signal intensity (absolute signal corrected for baseline) as a function of the number of echo times for (**a**) PCr, T_2 = 164 ± 10 ms; (**b**) PDE, T_2 = 346 ± 40 ms; (**c$_1$**) Pi, T_2 = 120 ± 28 ms, respectively, in a voxel of the calf muscle of a healthy male volunteer; (**c$_2$**) Pi, T_2 = 135 ± 15 ms in breast glandular tissue.

Conclusions: 3D AMESING at 7T with spherical k-space sampling is a promising tool for ^{31}P MR spectroscopy. Here we tested its application to calf muscle and breast glandular tissue and calculated T_2 values for some ^{31}P metabolites in sample volumes as small as 39 ml. Our data agree well with data published previously, which were acquired in sample volumes a factor 3 to 4 times larger. SNR of the SNR-weighted average spectra were up to 210 % larger than the SNR of the FID spectra acquired in the first shot of the sequence.

References:
[1] W.J.M. van der Kemp, V.O. Boer, P.R. Luijten, J.P. Wijnen, and D.W.J. Klomp, MRM (in press).
[2] W. Bogner, M. Chmelik, A.I. Schmid, E. Moser, S. Trattnig, and S. Gruber, MRM 62:574–582 (2009).



a **b**

Fig.4. (**a**) SNR weighted ^{31}P MR breast spectra and (**b**) FID ^{31}P MR spectra of a healthy female volunteer.