Localised ^{31}P MRS with a modified SPECIAL pulse sequence in mouse skeletal muscle at 7T

Isabell K. Steinseifer[1], Patrícia M. Nunes[1], Marnix C. Maas[1], Tom W.J. Scheenen[1,2], Andor Veltien[1], Ralf Mekle[3], Rolf Gruetter[4], and Arend Heerschap[1]
[1]*Radiology, Radboud University Nijmegen Medical Centre, Nijmegen, Netherlands,* [2]*Erwin L. Hahn Institute for Mgnetic Resonance Imaging, Essen, Germany,*
[3]*Physikalisch-Technische Bundesanstalt, Berlin, Germany,* [4]*EPFL, Lausanne, Switzerland*

Introduction

To study energy metabolism in muscle, brain and liver ^{31}P MRS is widely used. Dynamic ^{31}P MRS examinations can uncover important metabolic processes, in particular in muscles. These examinations are commonly performed without localisation beyond that of the RF coils, because of the relatively low signal to noise ratio (SNR) of ^{31}P and because of its simplicity and robustness. However, in many applications real localisation is desirable; e.g. to focus on specific muscles, or lesions, to avoid artefactual bone signals or to have the option of absolute quantification via phantom replacement. For localised ^{31}P MRS it is common to use an ISIS or a spectroscopic imaging sequence, which require multiple steps (8 or more) to achieve localisation. Single shot localisation by STEAM suffers from substantial signal loss. Recently, localisation by a semi-LASER sequence was proposed, which has the advantage of homogenous slice excitation by the adiabatic pulses [1]. However, the long TE of this sequence (> 23 ms) prevents the acquisition of J-modulated spin systems such as ATP.

Therefore we introduce in this study localised ^{31}P MRS by the SPin ECho, full Intensity Acquired Localised (SPECIAL) sequence, which has a 2 step adiabatic slice selection and combines the advantages of ultra-short echo times (TE of ~10 ms) with full sensitivity by spin echo application [2,3]. In particular, J-coupled multiplets and metabolites with short T2 relaxation times benefit from an improved SNR at the short TE. Improved SNR for ^{31}P MRS can be achieved at higher magnetic fields, but at the cost of RF inhomogeneities and increased chemical shift artefacts in slice selection. This can be overcome by adiabatic slice selective pulses with large bandwidths. For this reason we perform SPECIAL in combination with GOIA-WURST(16,4) pulses [4], which give a good uniform excitation, a very wide BW, while RF pulse duration and power are still comfortably within SAR limits at high field strengths [5]. In this study we demonstrate the performance of ^{31}P SPECIAL MRS on the mouse leg during ischemia at 7T.

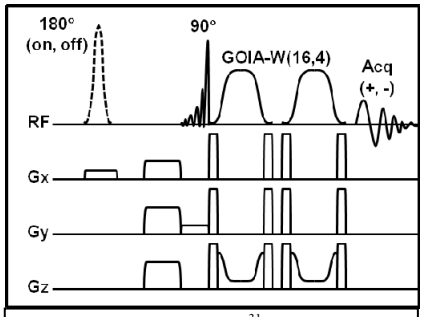

Fig. 1Sequence diagram of ^{31}P SPECIAL with implemented GOIA-W(16,4) refocusing

Method

The SPECIAL sequence combines one-dimensional image-selected in vivo spectroscopy (ISIS) with slice selective SE (Fig. 1). To obtain full localisation three orthogonal slice selections were needed: 1. The 180˚ adiabatic inversion pulse of the ISIS-block was executed in alternate scans, while switching the phase of the receiver at the same time. 2. The use of an asymmetric slice-selective 90° excitation pulse allows ultra-short TE. 3. For 180° refocusing two adiabatic GOIA-W(16.4) pulses are used. Each GOIA-W(16,4) pulse has a maximum RF power of 0.817 kHz, a BW of 20 kHz and a pulse duration of 3.56 ms.

The in vivo mouse measurements were performed on a 7T animal system (Clinscan, Bruker BioSpin GmbH, Rheinstetten, Germany), operating at 121.6 MHz for ^{31}P and 300.4 MHz for ^{1}H. An in-house developed three turn Tx/Rx ^{31}P solenoid coil surrounded by a ^{1}H Alderman-Grant coil was used for ^{31}P MRS and ^{1}H imaging. ^{1}H localisation images have been achieved with the body coil of the scanner. For all measurements we have chosen for a repetition time TR of 8 s, to avoid T_1 saturation effects, since the T_1 relaxation times for phosphocreatine (PCr) and inorganic phosphate (P_i) are 4.0 ± 0.2 s and 6.3 ± 1.0 s, respectively [6]. A ^{31}P FID measurement (TR = 8s, 32 averages, TA = 4:17 min) of the whole mouse leg was achieved for comparison reasons. For ^{31}P SPECIAL MRS a VOI of 5×5×5 mm^3 = 125 µl was positioned in a leg muscle of a wild type mouse (Fig. 2). Further measurement parameters were: spectral width = 3 kHz, vector size = 2048, TE = 11.4 ms, 32 averages and a resulting acquisition time of TA = 4:48 min. After causing ischemia in the mouse leg, a dynamic series of six localised ^{31}P MRS measurements within the muscle were performed.

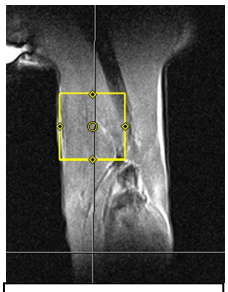

Fig. 2 Localised 5×5×5 mm^3 voxel in one muscle of a mouse leg.

Results and Discussion

The ^{31}P MR spectra of an FID of the whole leg (TA = 4:17 min) and of the SPECIAL localised measurement (TA = 4:48 min) are displayed in Fig. 3, in a range of -11 – 7 ppm. In both spectra P_i (5.0 ppm), PCr (0.0 ppm), γ-ATP (2.5 ppm) and α-ATP (7.5 ppm) are resolved. The SPECIAL acquisition is already under an ischemic situation, as it can be seen by a P_i increase and PCr decrease. The spectrum of the FID measurement shows some artefacts, most likely caused by contamination of the bones within the field of view of the coil, which are not visible in the localised SPECIAL spectrum. The SNR of the SPECIAL acquisition is 63 for a volume of 125 µl, whereas the FID measurement has a SNR of 66 with a field of view of the coil of 885 µl, which corresponds to an increase of 7 times SNR. In Fig. 4 a dynamic measurement of ischemia in the mouse leg is shown. During ischemia, PCr is converted into P_i, which causing a depletion of the PCr, whereas P_i increases significantly.

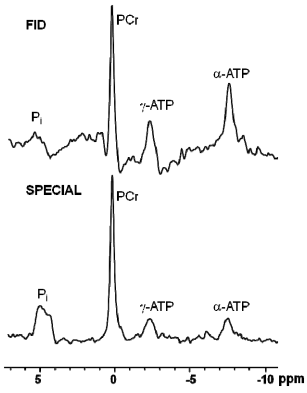

Fig. 3 ^{31}P FID and localized SPECIAL spectra of mouse leg.

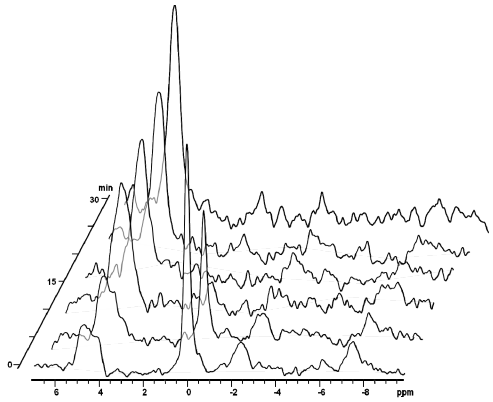

Fig. 4 Localised ^{31}P spectra of a 125 µl voxel in a mouse muscle during ischemia at 7T.

Conclusion

With the ^{31}P SPECIAL acquisition sequence we were able to perform localised ^{31}P MRS in a 125 µl small voxel inside a muscle of a mouse leg at 7T, within a comparable time resolution and a similar SNR as a whole leg FID measurement. Because of the good localisation signal contamination from bones and other structures can be avoided. The time resolution of the ^{31}P MRS acquisition was sufficient to follow metabolism during ischemia in a selected muscle.

References

[1] M.Meyerspeer et al., Magn.Reson.Med. 65: 1207-1215 (2011).
[2] V.Mlynárik et al., Magn.Reson.Med. 56: 965-970 (2006).
[3] R.Mekle et al., Magn.Reson.Med. 61: 1279-1285 (2009).
[4] I.Steinseifer et al., ISMRM 2011, Program number 1431.
[5] O.C.Andronesi et al., J.Magn.Res. 203: 283-293 (2010).
[6] W.Bogner et al., Magn.Reson.Med. 62: 574-582 (2009).

Acknowledgements Funded by FAST Marie Curie Research and Training Network (MRTN-CT-2006-035801) and KWF program grant.