# Interleaved $^{1}H/^{31}P$ STEAM Spectroscopy of Exercising Human Gastrocnemius Muscle at 3 Tesla

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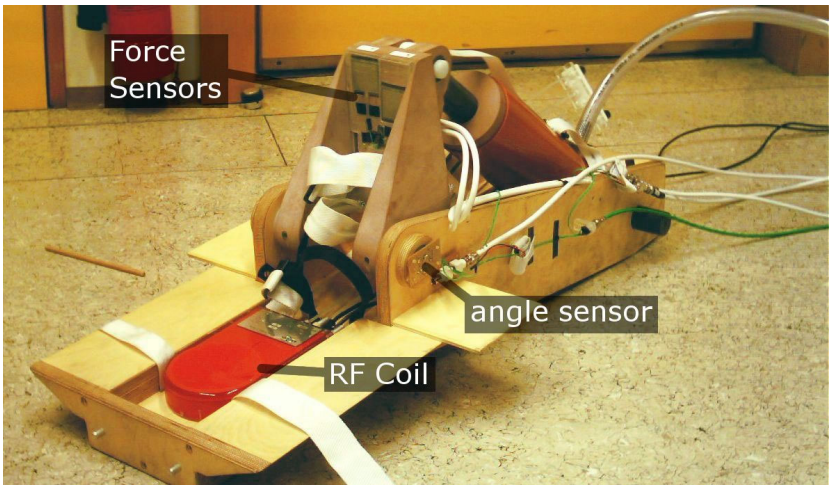
**Purpose/Introduction** Proton and phosphorus magnetic resonance spectra can provide complementary information on tissue metabolism. Acquiring two sets of spectra in consecutive experiments is time-consuming and furthermore may result in undesirably modified test conditions, e.g. due to fatigue during studies of exercising muscle. Whilst $^{31}P$ MRS has long been used for investigation of exercising muscle, interest in $^{1}H$ spectroscopy of muscle tissue has increased over recent years [1]. In particular, the possibility to quantify changes in lactate concentration and compare them with changes in pH, PCr and $P_i$ during exercise will remove a long-standing technical limitation to the study of the regulation of glycolysis, and also of cellular acid-base buffering mechanisms [2]. An interleaved STEAM sequence was developed to acquire localised $^{1}H$ and $^{31}P$ spectra from two independently positioned voxels in a single experiment, which has the additional benefit of NOE enhancement of the $^{31}P$ spectra. This work demonstrates the feasibility of interleaved acquisition of $^{1}H$ and $^{31}P$ spectra during plantar flexion in a pneumatic exercise rig.

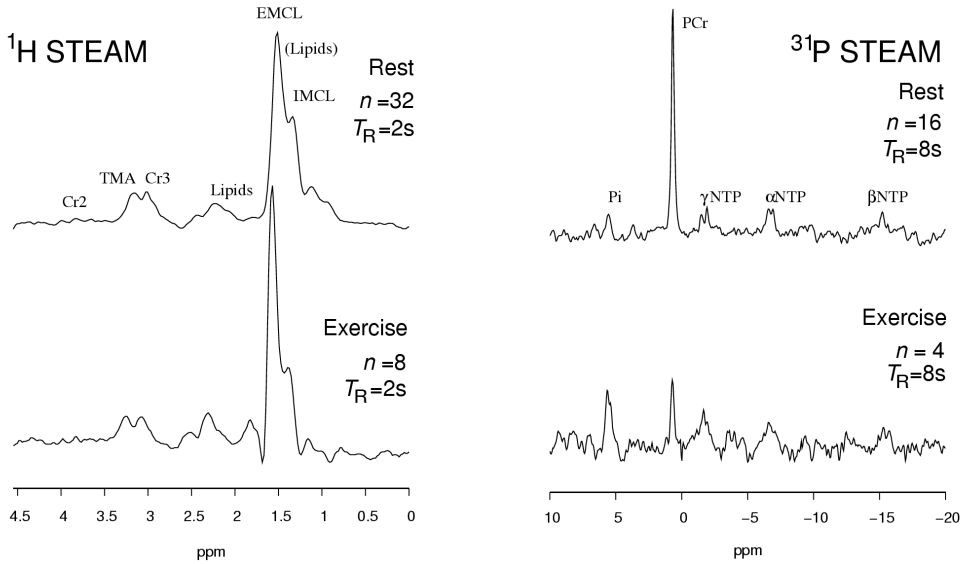
**Methods** Interleaved acquisition of $^{1}H$- and $^{31}P$ spectra with STEAM localisation was implemented on a 3T Bruker Medspec whole-body scanner via the MultiScanControl tool. The size, shape and position of the two voxels and other sequence parameters can be chosen independently. The integer number of excitations/acquisitions of $^{1}H$ spectra per $^{31}P$ excitation can be chosen to optimise $T_R$ for the respective metabolites. $T_1$ of $^{1}H$ metabolites is typically on the order of 1 s [3] while $^{31}P$ metabolites have significantly longer $T_1$s, ranging from 3 s to 6 s at 3 Tesla [4]. A reasonable acquisition ratio is therefore $^{1}H:{}^{31}P = 4:1$, yielding $T_R$s of e.g. 2 s:8 s and a time resolution of 16 s (for minimum phase cycling). CHESS was used for efficient water suppression.




A non-magnetic rig (Fig. 1) was constructed for plantar flexion exercise with defined force during dynamic NMR studies. Whilst pushing a pedal against a pneumatic piston ($V$ = 1.7 l) the calf of the extended leg lies on a double tuned transmit-receive surface coil ($d$ = 10 cm) which is counter-sunk in a wooden frame. By varying the pneumatic pressure, pedal force can be adjusted arbitrarily e.g. to match the subject's MVC – even remotely, during the NMR measurement, and can be modified dynamically. Exercise is monitored continuously by force and position sensors on the pedal.

**Results** The good performance of the interleaved $^{1}H/^{31}P$ STEAM was verified using a two-compartment test object [4]. In vivo $^{1}H$ spectra of resting human calf muscle (5 subjects) were equivalent with standard STEAM experiments and with the interleaved $^{1}H/^{31}P$ STEAM sequence, while $^{31}P$ *SNR* was increased due to NOE by a factor of 1.34 ± 0.06. Repetition time was $T_R$ = 2 s for $^{1}H$ spectra (left) and $T_R$ = 8 s for $^{31}P$ spectra (right). $T_E$ = 8 ms, $T_M$ = 30 ms, BW = 2.5 kHz, 1024 data points. VOIs were 1.7 $cm^3$ ($^{1}H$) and 34 $cm^3$ ($^{31}P$).

Spectral quality was sufficient for quantification of creatine (Cr), choline (TMA) and extra- and intramyocellular lipid (EMCL & IMCL) from $^{1}H$ spectra and $P_i$ and PCr in $^{31}P$ spectra, even during exercise. Significant $PCr/P_i$ changes could be achieved using the pneumatic exercise rig without deterioration of spectra e.g. by motion (Fig. 2).




**Discussion/Conclusion** Interleaved acquisition of STEAM spectra of $^{1}H$ and $^{31}P$ at 3 Tesla was demonstrated to be feasible during plantar flexion exercise. Interleaved acquisition $^{1}H$ spectra are equivalent to standard acquisition, and there is an *SNR* benefit in $^{31}P$ spectra. Future developments will focus on implementation of multiple $T_E$s for protons during one $^{31}P$ MRS acquisition, lactate editing and adiabatic water suppression.

**References**

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