Spectrally selective 3D-TSE imaging of phosphocreatine in the human calf muscle at 3T

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Introduction: Functional properties of skeletal muscle in vivo, both in healthy and disease state, have been primarily studied with the use of ^{31}P MR Spectroscopic techniques (MRS) [1]. Localized MRS methods can provide quantitative information about the concentration of several metabolites such as adenosine triphospate (ATP) and phosphocreatine (PCr) as well as inorganic phosphorus (Pi). However, these methods suffer from long acquisition times and coarse resolution, limiting their potential use in the clinical setting. Imaging of a single metabolite (i.e. PCr) can be achieved at a much higher spatial and temporal resolution, with the use of spectrally selective imaging methods [2,3], which can give valuable insight into the biomechanical and functional properties of the human skeletal muscle. In this study, we report the implementation of a 3D spectrally selective turbo spin echo (TSE) sequence and show the feasibility of PCr imaging in human calf muscle on a 3T Siemens clinical scanner.

Methods and Materials: All the experiments were performed on a 3T Siemens clinical scanner (MAGNETOM Tim Trio, Siemens Medical Solutions, Erlangen, Germany) using a dual-tuned ^{31}P/^{1}H quadrature volume coil (Rapid MRI, Ohio). A fully centric 3D-TSE sequence was developed using the 'SequenceTree' software [4]. We used an echo spacing of 26 ms and an echo train length (ETL) of 24 with 26 ms effective echo time, which eliminates any contamination from ATP signal [5]. The acquisition bandwidth was 2.5 kHz with field of view (FOV) of 220 x 220 x 200 mm and acquisition matrix size of 48 x 48 x 8, resulting in voxel size of 0.525 ml. A 12 s repetition time (TR) was used, resulting in acquisition time of 3 min and 12 s per average. The closest peak to PCr is that of γ-ATP (2.5 ppm), which at 3T gives a peak separation of 130 Hz. A narrow-band 16 ms Gaussian pulse was designed to selectively excite only the PCr peak. The bandwidth of the pulse was measured by acquiring a series of images of a 1 lt bottle containing 85% solution of phosphoric acid. The scanner's transmit frequency was incremented in 20 Hz steps from 300 Hz below the resonance frequency of Pi to 300 Hz above. The selectivity of the pulse was confirmed by acquiring images of three phantoms containing 50 mM of ATP, PCr and Pi respectively by centering the transmit frequency on each respective peak. Imaging experiments were performed on five healthy volunteers (age between 29-39 years). Four external phantoms were used with known concentration (PCr with 25 mM and 50 mM, and Pi with 25 mM and 50 mM) that will be used for quantification of the metabolites in the muscle by additional knowledge of the B1 characteristics of the coil (not shown here). Anatomical images were also acquired using a standard 3D-TSE sequence for ^{1}H with resolution of 1.7 x 1.7 x 5 mm and the same FOV and orientation as in the ^{31}P image. Relaxation parameters (T_1 and T_2) were measured on the same volunteers using unlocalized spectroscopic methods.

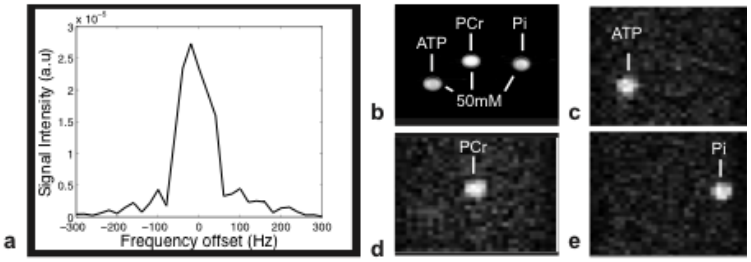

Fig. 1. **a**) Bandwidth profile of the 16 ms spectral-selective Gaussian pulse. (FWHM was 125 Hz). **b**) Proton image of 50 mM phantoms of ATP, PCr and Pi. Spectrally selective images acquired with the pulse centered at **c**) ATP, **d**) PCr and **e**) Pi peak.

Results and Discussion: The bandwidth of the pulse was estimated from the full-width-at-half-maximum (FWHM) of the peak shown in Fig.1.**a**. at 125 Hz. The spectral selectivity of the pulse was additionally confirmed from the images acquired with the pulse centered on the resonant frequency of each of the three phantoms shown in Fig.1.**b**-**e**. The T_1 and T_2 relaxation values calculated from the data were 5.57±0.26 s and 365±38 ms respectively. A typical ^{31}P spectrum of the human calf muscle, shown in Fig.2.**a**, (acquired using TR of 30 s and four averages). An axial and a coronal slice from a 3D image with SNR of eleven to one, acquired with five averages (16 min), is shown in Fig.2.**b**. Fig.2.**c** shows the anatomical ^{1}H image from the same volunteer. Bilinear interpolation was applied to the ^{31}P images that resulted in the same matrix size as the ^{1}H image.

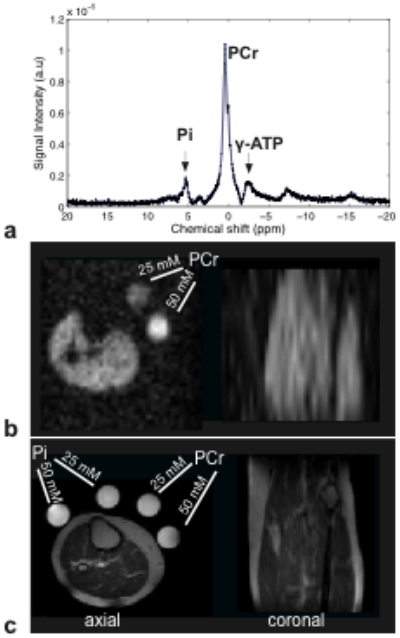

Fig. 2. **a**) ^{31}P spectrum from the calf muscle of a healthy volunteer. **b**) Axial (left) and coronal (right) slices from a PCr selective image of the calf muscle of the same volunteer. Bilinear interpolation was applied to the ^{31}P images that resulted in the same matrix size as the ^{1}H image shown in **c**.

Conclusion: A spectrally selective 3D-TSE sequence was implemented to image PCr in the human calf muscle with high SNR on a 3T clinical system using a dual-tune ^{31}P/^{1}H quadrature volume coil in a clinically feasible scan time.

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