High-Resolution Echo-Planar Spectroscopic Imaging of Human Calf

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Target audience

Physicists working in MR spectroscopy and signal processing; physiologists and clinicians interested in lipid metabolism.

Purpose

The main aim was to develop a high-resolution echo-planar spectroscopic imaging (EPSI) sequence, to investigate the feasibility of this method for assessing extra- (EMCL) and intramyocellular (IMCL) lipids, and to visualise the bulk magnetic susceptibility (BMS) shifts of EMCL spectral lines in more detail.

Methods

Six healthy volunteers participated in this study. Median age and body mass index (BMI) were 30.5 years (range: 22-61), and 23.3±1.5 kg/m^2 (range: 21-25.5), resp. The trapezoidal echo-planar readout gradient train was implemented into a standard PRESS spectroscopic imaging sequence. Experiments were performed on a 3 T scanner (Achieva, Philips). A circular two-element coil (diameter 20 cm) served as the receiver. 2D PRESS EPSI was performed in the transversal plane by means of 64×64 spectral matrix; FOV 192 mm; nominal voxel size 3×3×15 mm; acquisition bandwidth 128 kHz; and, TR/TE = 1500/38 ms. One and four signal averages were used for non-water and water suppressed scans, resp. Acquisition times were 1 min 36 sec and 6 min 24 sec, resp. The period of readout gradients was 1.6108 ms. Readout gradient waveforms consisted of linear ramps of 0.1566 ms duration, a constant plateau (0.4922 ms) and amplitude 15.66 mT/m. B_0 homogeneity was improved by first order shimming. Water suppression was performed using band-selective pre-pulses. An acquisition of two interleaved gradient echo trains (each with 256 echoes) was performed in order to increase spectral bandwidth. Beginning of the second echo train was shifted about half period of the readout gradients. This approach resulted in the spectral bandwidth of 9.72 ppm. 128 echoes arising from positive and negative readout gradients were processed for each element of the receiver coil separately, i.e., four (k_x, k_y, k_t) = (64,64,128) data matrices were processed. An optimized 2D Hanning filter[1] was applied across the k_x and k_y directions to reduce signal bleeding. Matrices were then zero-filled to size (64,64,512). The first FFT was performed along the k_t axis. Chemical shift artifacts caused by readout gradients were removed using a first-order phase correction[2]. Data processing continued with 2D FFT along k-space dimensions. The voxel spectra were then corrected for the shifts caused by B_0 deviations. Magnitude voxel spectra of four data matrices were summed. The spectra were averaged from defined volume of interest (VOI) (Fig. 1) and fitted by LCModel. Complex FIDs, were computed by inverse FFT of the magnitude spectra[2]. Lipid content in volume % was computed using methylene (-CH_2-)n intensity of the voxels with a 100% fat content as internal reference. Spectrum of tibial bone marrow was used for this purpose.

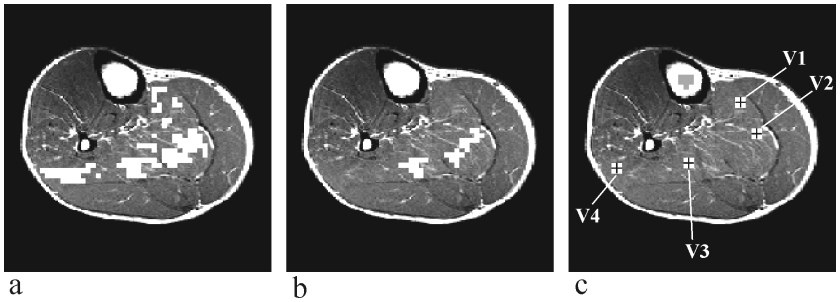

Fig. 1: (a, b, c) VOIs in soleus muscle. Reference fat VOI is indicated by grey pixels in tibial bone marrow (c).

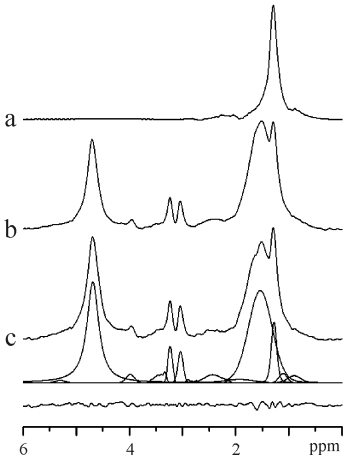

Fig. 2: Spectra of (a) reference fat, (b) m. soleus (VOI, Fig. 1a), (c) m. soleus (VOI, Fig. 1b) and LCModel fits.

Results

Figure 2a shows reference fat spectrum. Typical spectra of soleus muscle are shown in Fig. 2 b, c. The most pronounced lines are residual water (4.7 ppm), creatine at 3.9 ppm, trimethyl ammonium containing compounds (3.2 ppm), total creatine (3 ppm), methylene line at ~1.5 ppm ($EMCL_{CH2}$), and 1.3 ppm ($IMCL_{CH2}$). Mean m. soleus IMCL content of the volunteers was 0.26±0.1 vol% (range: 0.17-0.42). Figure 3 shows spectra with more complex BMS shifts of $EMCL_{CH2}$ lines. Spectra reveal splitting of $EMCL_{CH2}$ intensities and their positions between 1.5 and 1.8 ppm.

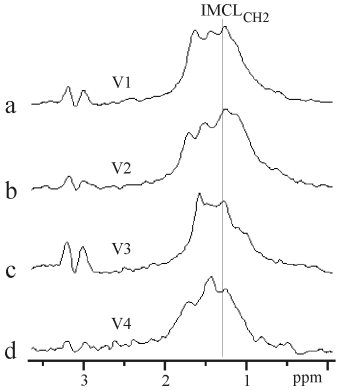

Fig. 3: Spectra computed from the VOIs V1-V4 (Fig. 1c).

Discussion

$IMCL_{CH2}$ and $EMCL_{CH2}$ lines dominate in typical spectra of m. soleus (Fig 2b, c). It was suggested that EMCL can be modeled by "long" cylinders with the axis at an angle θ relative to B_0[3]. According to this model, the $EMCL_{CH2}$ line shift ranges from 0.2 ppm to -0.1 ppm relative to $IMCL_{CH2}$ corresponding to a change in orientation $0^o \leq \theta \leq 90^o$. Model of long cylinders agrees well with the spectra obtained from the larger VOIs (Fig. 2b, c). However, this model is unable to explain spectra originating from small VOIs shown in Fig. 3. $EMCL_{CH2}$ signals are split into more well resolved peaks. Moreover, $EMCL_{CH2}$ spectral line shifts are increased up to 0.5 ppm relative to $IMCL_{CH2}$. This finding reveals that BMS effects are more complex than previously observed.

Conclusion

This study demonstrates that high-resolution PRESS EPSI of the muscle lipids is feasible on standard 3T clinical scanners. High spatial resolution enables assessment of muscle lipids in noncontiguous and irregularly shaped VOIs. The small voxels enabled visualisation of $EMCL_{CH2}$ spectral lines splitting and their BMS shifts.

References

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