Absolute quantification of ^{31}P muscle MRS using B_1-field mapping

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Aims: The aim was to develop a simple method for the determination of the inhomogenous B_1 field associated with ^{31}P surface coils for use in absolute quantification of phosphagen concentrations in human forearm muscle using depth resolved surface coil spectroscopy (DRESS).

Introduction: The principle of reciprocity states a proportional relationship of the sensitivity during transmission of the RF-pulse relative to the amplitude of the received NMR signal using a receive-transmit RF-coil [1]. This relation has been used for absolute quantification in single voxel studies under the assumption that the B_1 field is homogenous throughout the voxel volume. The local B_1-field strength in each examination can be obtained using repeated acquisitions with different RF-pulse amplitudes ('transmit gain', 'flip angle') [2, 3]. Surface coils combined with large voxel volumes are desirable during dynamic studies of muscle metabolism; however the large voxel volume combined with the highly inhomogeneous B_1-field associated with a small surface coil makes the assumption of homogenous B_1-field inside the voxel inappropriate. The inhomogeneity can be corrected by the use of a map of the spatial distribution of the B_1-field acquired either through computer simulation, or through measurement of the field. There are two major advantages by actually measuring the B_1 distribution; it makes the registration of the map against MR-images easier and also a measured B_1-field compensates for imperfections in the coil design. The latter is not easily incorporated into a computer model. DRESS is an attractive choice for use in muscle metabolism studies as it minimizes the dead time between an RF-pulse and the acquisition of resonances with short T_2. In addition, the excitation profile is relatively insensitive to changes in flip angle

Material and methods: Data were acquired using a 1.5 T clinical whole body MR-scanner. A 3"/1" elliptical ^{31}P receive-transmit surface RF-coil (the Institute for Biodiagnostics, National Research Council, Canada) were used for acquisition of ^{31}P spectra. The proposed method contains 9 steps where step 3 to 9 is repeated in each examination.

Subject: One healthy volunteer were examined four times at three different occasions.

Data acquisition:

1. **Mapping of the vector B_1 field associated with the surface coil.** Using an experimental setup containing a small search coil, a MR-compatible 3-dimensional (3D) search coil positioning system, a broadband preamplifier, circuits for coupling control, a scalar analyzer (RF-sweeper, Morris Instruments Inc., Canada) and a computer, see figure 2. Only the part of the measured B_1-field perpendicular to the B_0-field was used in the analysis. The resolution of the mapping was 1 x 1 x 1 cm.
2. **Registration of the mapped coordinate system against a coordinate system fixed relative to the coil.** This registration was performed using an experiment where MR-visible markers attached to the coil were imaged in the MR-scanner together with the 3D positioning system with the search coil replaced by a MR-visible marker at known positions in the mapped coordinate system.
3. **Acquisition of localizer images using the body coil and registration of the coil coordinate system against the magnet bore coordinate system during the examination.** This was performed using MR-visible markers attached to the coil, see figure 1.
4. **Acquisition of DRESS spectra at several different RF-pulse amplitude values.** A slice thickness of c. 10.0 mm was prescribed c. 1.00 cm above the coil surface, repetition time (TR) set to 5 s and 32 transients. The arm was positioned relative to the coil using a fixation device.
5. **Acquisition of spectra from an external reference at four different RF-pulse amplitude values.** The reference compound used for external referencing was dimethyl methylphosphonate (DMMP), slice thickness 20 mm, TR 3.00 s and 16 transients. The T_1 relaxation time of the DMMP was determined to be 890 ms.

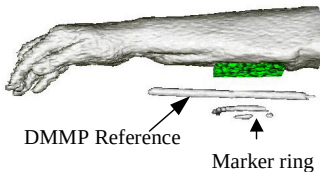

Fig. 1. Volume rendering of forearm showing the reference position and the MR-visible marker. The RF-coil position is drawn in green color.

Fig. 2. The experimental setup used for mapping of the B_1-field.

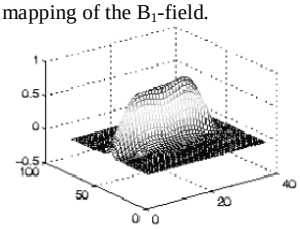

Fig. 3. The mapped B_1-field 1 cm above the coil surface.

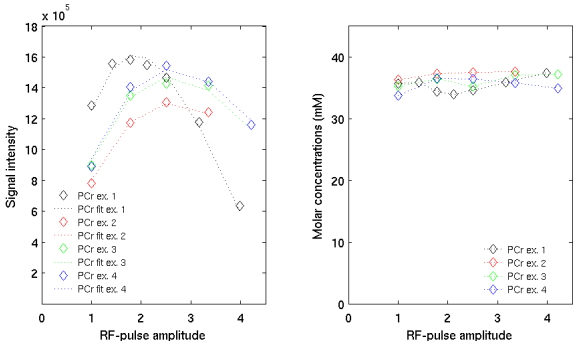

Fig. 5. Left panel: Quantified signal intensities of the PCr resonance and the model fit in all examinations for the different RF-pulse amplitudes. Note the differences in max amplitude between the examinations. Right panel: Absolute quantified concentrations for corresponding signal intensities. Note how the flip angle dependency and the max amplitude differences have been corrected.

Data analysis:

6. **Segmentation of muscle and subcutaneous fat included in the DRESS voxel using localizer images.** The phosphagen content in subcutaneous fat was assumed to be negligible and therefore was only the part of the DRESS voxel containing muscle included in the analysis, see figure 4.
7. **Time domain quantification of muscle and reference spectra using the AMARES algorithm in jMRUI [4, 5].**
8. **Determination of a scaling factor of the mapped B_1-field through least square optimization of measured signal intensities from the DRESS voxel.** This was performed using a model describing signal amplitude as function of concentration * receiving amplification, mapped B_1-field distribution, RF-pulse amplitude, T_1 and TR.
9. **Determination of receiving amplification through least square optimization of measured signal intensities from the DMMP reference.** Using the same model as in step 8 solving for receiving amplification and B_1-field strength.

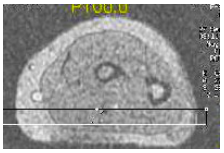

Fig. 4. The DRESS voxel position. Note the fat layer.

Results: The B_1 field map in a plane parallel to the coil is shown in figure 3. The acquired spectra from both the DRESS voxel fulfilled the relationship predicted by the model and the B_1-field map, see figure 5. The measured concentrations were (in mM ± SD) PCr 36.1±0.8, P_i 4.6±0.6 and ATP-β 9.2±0.6, the total phosphorous content was 68.0±0.3 mM.

Conclusions/discussion: The results show a high reproducibility of the concentration values from one single subject, further evaluation using a calibration phantom and several healthy subjects are required to determine the intersubject reproducibility and accuracy of the method. The signal to noise ratio (SNR) available from the prescribed voxel enables dynamic studies of muscle metabolism. A high reproducibility in absolute determinations of muscle metabolites is very important for the possibility of making quantitative comparisons between patients and healthy controls at several muscle disorders.

References: [1] Hoult, DI.: Concepts Magn Reson 12:173-187, 2000. [2] Kreis R. et al: J Magn Reson 149:245-250, 2001. [3] Helms G.: NMR Biomed 13:398-406, 2000. [4] Naressi, A. et al: MAGMA, 2001. [5] Vanhamme, L. et al: J Magn Reson 129:35-43, 1997.