^{1}H/ ^{31}P birdcage coil combined with dedicated multi-element ^{31}P receive coil for optimal ^{31}P MRSI of the tibialis anterior

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Introduction

Phosphorous MRS has been widely used to study bioenergetics of healthy and diseased muscles *in vivo.* Facioscapulohumeral muscular dystrophy (FSHD) is a major muscular dystrophy affecting several skeletal muscles including the tibialis anterior in the lower leg. This superficial muscle can be used isolated from other muscles and thus offers advantages to be assessed by MRS during exercise. Commonly ^{31}P MRS of skeletal muscle is performed with surface or (half) volume RF coils both for excitation (Tx) and receive (Rx), covering at least the muscle of interest [1]. However, smaller surface coils provide increased signal to noise (SNR) and arranged in a multiple array for Rx together with a separate volume Tx coil also offers more experimental flexibility without compromising muscle coverage. This may provide the necessary SNR for time-resolved ^{31}P MR spectroscopic imaging (MRSI) of skeletal muscle during exercise. Therefore the aim of this study was to design, built and test a ^{31}P/^{1}H transmit/ receive (TxRx) birdcage coil combined with an array of ^{31}P receive coils to achieve a high SNR focused on the tibialis anterior.

Materials and Methods

The coil setup consists of a quadrature TxRx ^{31}P/ ^{1}H birdcage coil (12 legs for each frequency) that can be detuned on the ^{31}P frequency leaving the tuning of the ^{1}H frequency intact. The ^{31}P/ ^{1}H birdcage coil can be combined with a 5 channel ^{31}P Rx array coil. The birdcage coil is based on the design of Matson et al dedicated for use at 1.5T [2]. PIN-diodes were placed in series with 4 of the 12 ^{31}P legs to detune the ^{31}P resonance during receive with the array Rx coils. Tuning and matching was achieved with a symmetric circuit with variable capacitors. The balancing was achieved by cable traps.

Each element of the receive array is 4 by 4.5 cm. The short side overlaps with its neighbouring elements to prevent coupling between the elements. The total coil size of all elements combined is 4.5 by 20 cm. A single element has an unloaded Q of 184, a loaded Q of 93 with an induction of 123 nH. The total resistance under loaded condition is 0,41Ω. To prevent impractical component values for preamp decoupling, the matching circuit as described by Reykowski et al [3] is implemented. This matching circuit has an extra variable in the calculations that can be used to achieve practical component values. The receive elements can be detuned on the ^{31}P frequency during ^{31}P transmit and have a ^{1}H trap to prevent high ^{1}H currents during ^{1}H transmit.

The new probe was tested at 3T (TRIO Siemens, Erlangen) on a cylindrical phantom (diameter 14 cm, length 18 cm, containing 75mM phosphate buffer, 79 mg/L $NiSO_4$, 0.02% sodium azide and 2% of agar), and also on a lower leg of a healthy volunteer. 3D ^{31}P MRSI was performed with a hard excitation pulse (333us), a Tr of 1030ms, matrix size8x8x8 (16x16x16 interpolated) with a interpolated nominal voxel size of 13cm^3 and total exam time of 8min.

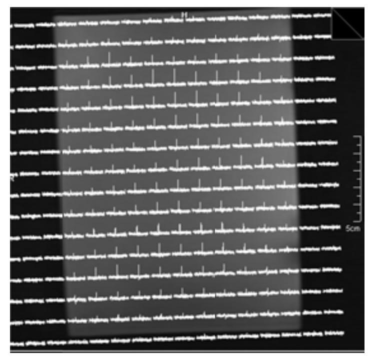


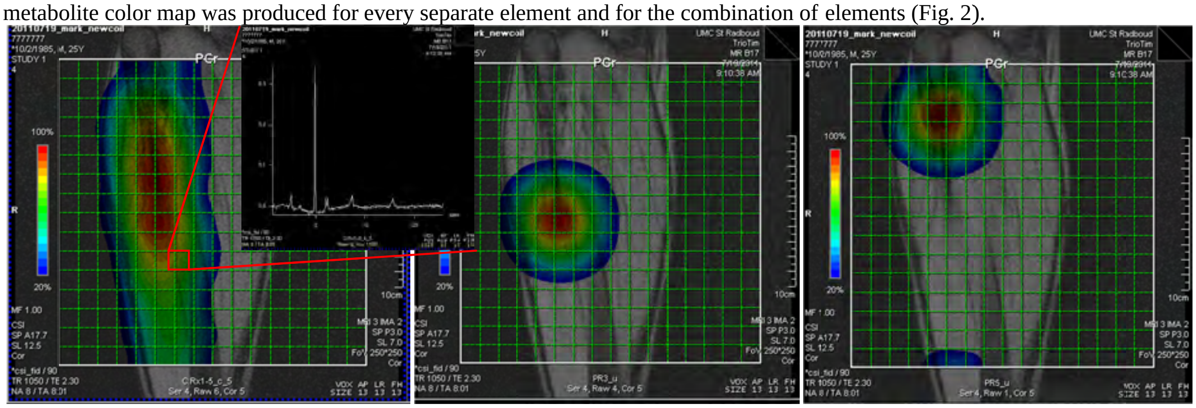
Image with ^{31}P

Results and Discussion

In the design of Matson [2] only one side of the ^{31}P legs had ^{1}H traps. At 3T we discovered that the legs that are resonant on ^{31}P need ^{1}H traps at both ends to prevent influence of the ^{31}P legs on the ^{1}H resonance of the coil. This was most likely caused by the higher frequencies corresponding to the higher magnetic field.

A ^{1}H Gradient Echo image of the phantom with conventional pulses shows the homogeneity of the ^{1}H field of the birdcage coil (Fig.1). Subsequent 3D ^{31}P MR spectroscopic imaging essentially also revealed a homogenous distribution of phosphorus signals, except at the outer edges of the coil (Fig. 1). Uneven excitation with these residual inhomogeneous RF-fields can be corrected by adiabatic excitation pulses.

The combination of the birdcage coil and the receive array coil was tested on a healthy volunteer. First ^{1}H Gradient Echo images with conventional pulses were acquired of the lower leg for background images. Second, receiving with the array coil, 3D 31P MRSI was performed. MR spectra with excellent SNR were obtained of small voxels from the anterior tibialis (Fig. 2). The signal of phosphocreatine was fitted and a metabolite color map was produced for every separate element and for the combination of elements (Fig. 2).



Conclusion: We developed a quadrature TxRx ^{31}P/ ^{1}H birdcage coil that generates homogeneous RF-fields at the ^{1}H and ^{31}P frequency at 3T, in combination with a dedicated 5 channel ^{31}P receive array with optimum SNR focused on the anterior tibialis. This paves the way for spatially and time resolved exercise experiments of this muscle.

References: [1] Kan et al NMR Biomed. 23:563 (2010); [2] Matson et al. MRM 42:173 (1999) ; [3] Reykowski et al, MRM 33:848 (1995),