Performance comparison of a form fitted coil array vs. a quadrature birdcage coil for ^{31}P MRS studies in the human calf at 7T

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Target Audience: Researchers who are interested in RF coil array design for X-nuclei applications.

Purpose: ^{31}P spectroscopy is often used for metabolic studies of skeletal muscle such as the human calf. Data quality is inherently improved at higher field strength due to higher sensitivity, increased spectral resolution and shorter T_1 relaxation times [1]. Additionally, higher specificity can be obtained when employing localized ^{31}P MRS to avoid signal contamination from outside the ROI [2]. Due to the smaller volume contributing to the signal, higher sensitivity of the RF coil is needed [3]. Phased arrays increase sensitivity near the RF coil at the cost of B_1 field homogeneity. Similarly sized volume coils produce a more homogeneous field but lack the high sensitivity in regions close to the coil. This abstract compares a cylindrically arranged 3 channel transceive array to a birdcage coil of comparable size.

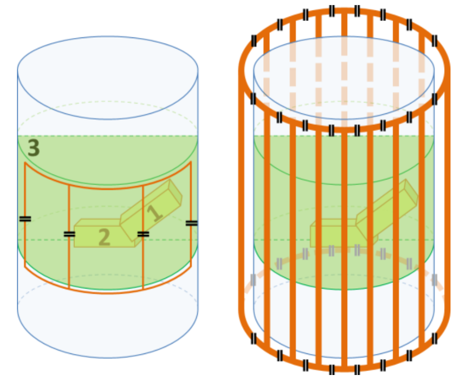

Fig. 1 *3-channel shared conductor array (left), 16-leg high-pass yellow birdcage (right). Three ROIs are defined as voxels (60x40x15mm³, boxes) in gastrocnemius medialis (1), and soleus muscle (2), and the lower half cylinder (3, shaded green area).*

Methods: 3D electromagnetic simulations were conducted for two 7 T ^{31}P RF coils, both designed for a dynamic localized ^{31}P spectroscopy in the exercising human calf with ROIs in the gastrocnemius medialis and soleus muscle (see Fig 1). The first design is a 3 element shared conductor array [4-6] with the following geometry: element size 10 x 6.4 cm^2, wire conductor width 1.5 mm and curvature diameter 14.9 cm. The second design is a 20 cm long 16-leg quadrature driven high-pass birdcage coil with a conductor width of 10 mm and a diameter of 18 cm, according to the dimensions of a commercially available dual tuned ^{31}P/^{1}H quadrature coil (Rapid Biomedical, Rimpar, Germany) previously used in spectroscopy studies [7]. Both coils were loaded with a 20 cm long quasi-cylindrical phantom (d = 14 cm) comparable to a human lower leg in shape (flattened top) and dielectric properties $\varepsilon = 50$, $\sigma = 0.25$ S/m. XFdtd (Remcom, State College, PA, USA) was used for 3D EM simulations and ADS (Agilent, Santa Clara, USA) for tuning (120.3 MHz), matching to 50 Ω (<-40 dB), decoupling (<-40 dB for the birdcage, <-16 dB for the array coil) and calculation of the scaling parameters [8]. RF coil performance was evaluated for each design using the SimOpTx toolbox (CMPBME, MedUni Vienna, Austria). For a valid comparison, the appropriate safety regulations according to the IEC60601-2-33 standard for volume and surface coils were considered and both coils were driven with the maximum allowed power. The B_1^+ distribution, as well as mean B_1^+ and relative inhomogeneity std(B_1^+)/mean(B_1^+) were calculated in each ROI. For receive comparison a figure of merit μ was calculated which is proportional to SNR [9, 10]. The ratios for B_1^+ and SNR between array and birdcage coil were calculated.

Birdcage vs. Array		GM	SOL	hCyl
mean B_1^+ [μT]	Birdcage (29.1 W)	10.1	10.7	10.3
	Array (12.2 W)	14.6	13.5	12.0
	Difference	***45%***	***27%***	***17%***
relative inhomo-geneity	Birdcage	3%	4%	8%
	Array	17%	9%	35%
	Difference (% points)	***14***	***5***	***27***
mean μ [a.u.]	Birdcage	0.10	0.09	0.09
	Array	0.38	0.26	0.27
	Ratio (AR/BC)	***3.9***	***2.8***	***2.9***

Tab. 1 *RF coil performance comparison in terms of mean B_1^+, relative inhomogeneity std(B_1^+)/mean(B_1^+) and μ (∝ SNR) in the three ROIs: half cylinder (hCyl), gastrocnemius medialis (GM), and soleus (SOL).*

Results: The maximum allowed power for the quadrature driven birdcage coil was calculated to be in the range of 29.0-29.2 W, depending on the total body mass (70-90 kg). For the coil array, the maximum permissible power within the local SAR limit of 20 W/kg for extremities was 12.2 W. Mean B_1^+, relative inhomogeneity, and mean μ for the three ROIs are summarized in Tab. 1. Higher B_1^+ values were observed for all three ROIs, with the highest increase in GM (45%) for the array coil, whereas homogeneity was consistently better for the birdcage coil. A minimum 2.8-fold increase (SOL) in SNR up to 3.9-fold (GM) could be observed. Fig. 2 shows the ratio maps for the B_1^+ and SNR (μ) distribution. The array performs better in the red area below isocontour 1.

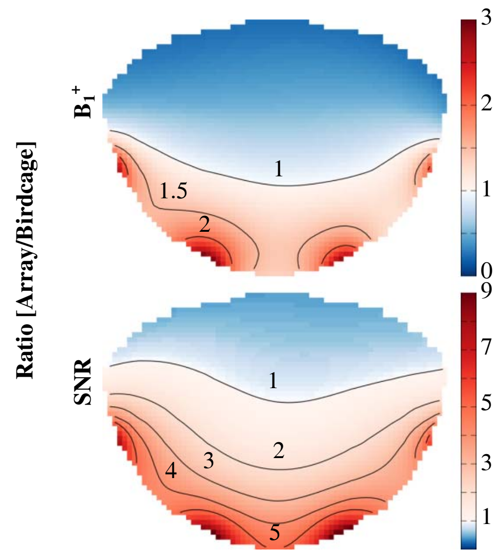

Fig. 2 *Ratio maps of the B_1^+ field (top) and SNR (bottom) distribution of the array coil over the birdcage coil with corresponding isocontours.*

Discussion: In good agreement to the hypothesis, a notable advantage of the array over the birdcage coil in terms of mean B_1^+ in the application-specific ROIs could be observed, with strongest improvement for the superficial gastrocnemius medialis muscle. The homogeneity within the muscle ROIs deteriorated by only 14 (GM) and 5 (SOL) percentage points, respectively. Since the higher B_1^+ can be used for shorter adiabatic pulses, the moderate loss in homogeneity is of minor importance. Additionally for the receive side a 3.9 (GM) and 2.8 (SOL) fold increase in SNR could be achieved with the surface coil design over the birdcage.

Conclusion: We showed that for localized ^{31}P spectroscopy experiments in the human calf muscle, where signal homogeneity over the whole leg cross-section is of minor importance, but high sensitivity in GM and SOL muscles is required, a form-fitted 3-channel RF coil array outperforms a 16-leg quadrature high-pass birdcage by increasing the available B_1^+ by 27-45% and improving SNR by a factor of up to 3.9.

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