8-channel double tuned ^{13}C-^{1}H transceiver phased array for ^{13}C MRS in human brain at 7T

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Introduction: Direct ^{13}C MRS is laborious due to the inherent low ^{13}C sensitivity and the ^{13}C-^{1}H hetero-nuclear *J* coupling, which further reduces the ^{13}C sensitivity. In order to enhance the sensitivity, ^{13}C MRS requires double tuned ^{13}C-^{1}H RF coils to operate ^{1}H decoupling during ^{13}C signal acquisition. In particular, ^{13}C MRS is currently performed using ^{13}C-^{1}H transceiver surface coils which provide high sensitivity at the expense of reduced field of view (FOV) [1, 2, 3]. Recently, a double tuned ^{31}P-^{1}H transceiver array was reported for ^{31}P MRS studies in human brain at 7T [4], resulting in improved sensitivity and increased spatial coverage. The aim of this study was to build a four channel ^{13}C - four channel ^{1}H transceiver array coil for ^{13}C MRS studies of the human brain at 7T. The performance of the coil was evaluated by bench measurements, EM simulations, and ^{13}C MRS measurements in vitro.

Methods: *Coil design*: A double tuned ^{13}C-^{1}H transceiver phased array was built, consisting of a concentric combination of a 4-channel ^{13}C array (88x80mm^2 rectangular loops) and a 4-channel ^{1}H array (120x90mm^2 rectangular loops), bent to a diameter of 23 and 26cm, respectively (fig. 1). The mutual coupling between neighbouring loops was minimized by adjusting the overlap, and the mutual coupling between the ^{13}C and the ^{1}H array coils was minimized by inserting an LCC trap circuit in each ^{13}C loop [5]. Common modes currents on the coaxial cables were minimized using bazooka baluns (for ^{1}H cables) and LC tank circuit and ^{1}H-bazooka (for ^{13}C cables). A copper shield was attached to the outer surface of the coil. Two TR-switches were built (for ^{13}C and ^{1}H), using Wilkinson power dividers, phases shifters, lumped elements lowpass (75MHz) and broadband (300 MHz) filters, pin diodes RF-switches and preamplifiers. *Bench measurements*: To evaluate the performance of the coil, S_{ij} parameters and full quality factors (Q) were measured at the ^{13}C (75 MHz) and ^{1}H (300 MHz) frequency with a Network Analyzer (E5071C, Agilent). The coil was loaded with a 15.6 cm diameter spherical phantom containing 15 mM glucose C_1 labelled in a solution of 1.2L distilled water and 0.8L dPBS. *Simulations*: FDTD simulations were performed using SEMCAD X (Speag, Switzerland). Three double tuned ^{13}C-^{1}H coil designs were compared: a linear ^{13}C-quadrature ^{1}H [1], a double quadrature ^{13}C-^{1}H [3] and a 4ch ^{13}C - 4ch ^{1}H, modelled with the same loops size. The coils were loaded with the head of the Duke model from "Virtual Family" (ITIS, Switzerland). B^1_+ and SAR_{10g} were measured at 75 and 300 MHz. The phases between the loops were adjusted using Matlab (The Mathworks, Natick, USA) in order to maximize the mean B^1_+ over the head. *MR measurements*: MR experiments were performed on a 7T human scanner (Siemens Erlangen/Germany). The performance of the coil was evaluated by measuring ^{13}C spectra of the glucose phantom without and with ^{1}H decoupling. Glucose β resonance was acquired using an adiabatic half passage (AHP) pulse for excitation (2ms) and continuous wave (CW) for ^{1}H decoupling during ^{13}C signal acquisition (vector size 2048, TR = 3s, BW = 20 kHz, acquisition time = 102ms, decoupling duration = 102ms, 64 averages).

Results: *Bench measurements*: The reflected power of all loops was better than -30dB (fig. 2). Isolation between loops was better than -10dB at 75 MHz and -15dB at 300 MHz. The LCC traps provided an isolation between the ^{13}C and the ^{1}H loops better than -20dB. The ratio of the unloaded and loaded Q was ~5 (350/70) for the ^{13}C loops and ~4 (280/70) for the ^{1}H loops, indicating good efficiency of the coil. *Simulations*: Fig. 3 shows the ^{13}C B_1^+ maps in the head transverse plane for the 3 different designs. All loops were driven with 1W power. The optimized phase for the double quadrature coil and for the array coil were close to the quadrature ((0°,90°), resp. (0°,90°,180°,270°)). Higher B_1^+ efficiency is achieved over a larger FOV with the array compared to the other coils. The local SAR was also reduced with the array configuration for these specific RF phase settings (Table 1). The $|\overline{B_1^+}|/\sqrt{SAR_{10g,max}}$ of the ^{13}C array is fourfold higher compared to a linear ^{13}C, and twofold higher compared to a double quadrature. Similarly, the $|\overline{B_1^+}|/\sqrt{SAR_{10g,max}}$ is almost twofold higher for the ^{1}H array. *MR measurements*: Glucose β resonance was detected at 96.6 ppm (fig. 4). The conversion of the glucose β doublet (a) into a singlet (b) when using ^{1}H decoupling indicates an excellent isolation between the ^{13}C and the ^{1}H arrays.

Conclusion: The ^{13}C-^{1}H double tuned array coil increases both transmit efficiency and FOV in comparison to a linear or double quadrature surface coil. The obtained in vitro ^{1}H-decoupled ^{13}C spectra of glucose β demonstrate the feasibility of a double tuned ^{13}C-^{1}H transceiver array coil for ^{13}C MRS measurements at 7T, allowing the extension of ^{13}C MRS in human brain at 7T.

References: [1] G. Adriany et al, JMR 125:178-184, 1997; [2] D.W.J. Klomp et al, MRM 55:271-278, 2006; [3] E. Serés Roig et al, MRM, 2014; [4] N.I. Avdievich, Appl. Magn. Reson. 41:483-506, 2011; [5] A. Webb et al, ISMRM 2010;

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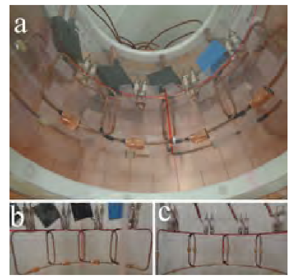

Fig 1: (a) 8ch double tuned ^{13}C-^{1}H transceiver array, composed of (b) a ^{13}C and (c) a ^{1}H 4ch transceiver arrays.

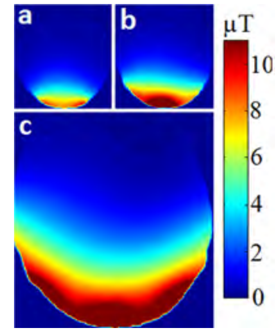

Fig 3: Simulated optimal ^{13}C B_1^+ for: (a) linear ^{13}C [1], (b) double-quad. [3], (c) 8ch array.

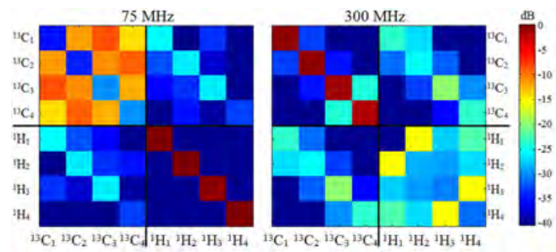

Fig 2: Coupling matrices at ^{13}C (left) and ^{1}H (right) frequency with the 2L glucose phantom.

	$\lvert\overline{B_1^+}\rvert$ $[\mu T]$ ^{13}C	^{1}H	$SAR_{10g,max}$ $[W/kg]$ ^{13}C	^{1}H	$\lvert\overline{B_1^+}\rvert/\sqrt{SAR_{10g,max}}$ ^{13}C	^{1}H
Linear coil [1]	0.46	0.23	0.82	0.53	0.51	0.32
Double quad.[3]	0.83	0.28	0.56	0.39	1.11	0.45
8 ch Array	1.33	0.31	0.37	0.2	2.18	0.69

Table 1: Comparison of SAR_{10g} and simulated transmit efficiency of three double tuned ^{13}C-^{1}H coil designs.

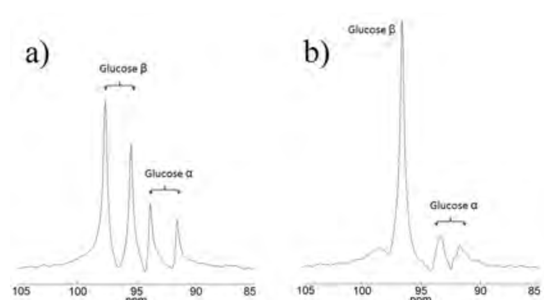

Fig 4: In vitro ^{13}C NMR spectra with glucose β on-resonance, without (a) and with (b) CW ^{1}H decoupling.