A Measurement Setup for combined Chlorine (^{35}Cl) and Sodium (^{23}Na) MRI of the Human Brain

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Target Audience: Scientists and physicians interested in the field of non-proton MRI

Purpose: ^{23}Na MRI has been performed for more than 25 years [1] and has evolved into a valuable tool for clinical research, since it provides non-invasive insights into cellular ion homeostasis and cell viability [2]. Recently, the first ^{35}Cl MR images of the rat brain [3] and the healthy human brain and muscle [4] were acquired. Chlorine (Cl^-) is the most abundant anion in the human body and is also involved in many physiological processes, e.g. volume regulation, transepithelial transport and the regulation of electrical excitability [5]. Therefore, a combined imaging of the Na^+ and Cl^- concentrations is highly desirable. ^{23}Na MRI in clinical research is often performed after morphological images were acquired and normally requires repositioning of the patient, since the quality of the ^1H channel of double-resonant coils is usually not sufficient for clinical examinations. For combined ^{35}Cl and ^{23}Na studies it is desirable that the examinations be performed in one coil without additional repositioning of the patient, since this would yield unfeasible examinations times. Therefore, we developed and tested a dual tuned head coil for combined ^{35}Cl/ ^{23}Na imaging.

Methods: Combined $^{35}Cl/^{23}Na$ MRI was conducted on a 7 T whole body MR system (MAGNETOM 7 T, Siemens AG, Healthcare Sector, Erlangen, Germany) using a dual tuned (^{35}Cl/ ^{23}Na), quadrature birdcage coil. It is made of a concentric design with a resonator diameter of 29 cm and a length of 27 cm. For evaluating sensitivity, two versions were built: Version 1: with ^{23}Na traps in the ^{35}Cl resonator; version 2: without ^{23}Na traps. Additionally, images with a dual tuned (^1H/ ^{23}Na) quadrature birdcage coil were acquired to evaluate the quality of the ^{23}Na channel. All ^{23}Na and ^{35}Cl MRI sequences were based upon a density-adapted 3D radial projection reconstruction pulse sequence [6].

On the workbench, the resonators were tuned and matched to the working frequencies of 29.1 MHz (^{35}Cl) and ^{23}Na (78.6 MHz) with S11s better than -20 dB, while the channel isolation was better than 25 dB. In the MR system, the B_1 efficiencies were measured by determining the transmit power required for a 180° pulse at a given pulse duration (1 ms) on a spherical 2.6 l phantom with 0.9% saline solution. B_1 homogeneity and SNR were investigated on version 1 of the birdcage (with ^{23}Na traps). Parameters: **^{35}Cl MRI:** TE/ TR = 0.5/ 180 ms; $\alpha = 90°/45°$; 4000 projections; $\Delta x^3 = 8$ mm^3; **^{23}Na MRI:** TE/ TR = 0.35/ 300 ms; $\alpha = 90°/45°$; 4000 projections, $\Delta x^3 = 4$ mm^3. SNR was determined according to the National Electrical Manufacturers Association (NEMA) definition [7], using the magnitude signal of noise-only images.

In vivo Imaging: **^{35}Cl MRI**: To minimize relaxation weighting and to fulfill SAR restrictions a long repetition time (TR = 82 ms) and a short echo time (TE = 0.5 ms) were used. Additional parameters: readout duration: T_{RO} = 5 ms; α = 90°; pulse duration: T_p = 800 µs; nominal resolution: $\Delta x^3 = (8\ \text{mm})^3$; Hamming filtering; acquisition time: T_{aq} = 10 min. **^{23}Na MRI**: TE = 0.3 ms; TR = 160 ms T_{RO} = 5 ms; α = 90°; T_p = 800 µs; $\Delta x^3 = (4\ \text{mm})^3$; Hamming filtering; T_{aq} = 10 min 40 s.

Results and Discussion: The measured Q values are shown in Table 1. The results for B_1 efficiency are given in Table 2. The change of Q drop for ^{35}Cl due to ^{23}Na traps displays quite nicely the 30% difference in B_1 efficiency (SNR ~ SQRT(1-Q_l/Q_u)). The change of ^{23}Na B_1 efficiency according to the change in Q drop would be 15%. The observed B_1 difference is larger (36%), since, in addition to the change in Q, the ^{23}Na B_1 pattern is changed when the ^{35}Cl birdcage is not blocked at the ^{23}Na frequency (anti-phase of B_1 at the higher frequency). The ^{35}Cl/ ^{23}Na coil exhibits good B_1 homogeneity (c.f. Fig 1, measured on a spherical phantom) in both channels. Phantom imaging revealed SNR values of 63 ± 3 (^{35}Cl MRI), 101 ± 3 (^{23}Na MRI: ^{35}Cl/ ^{23}Na coil) and 95 ± 3 (^{23}Na MRI: ^1H/ ^{23}Na coil). Correction for different voxel volumes yielded a 12.7-smaller SNR for ^{35}Cl MRI compared to the ^{23}Na imaging (sequence parameters were chosen so that relaxation effects can be neglected). The measured SNR ratio lies well within the theoretically expected range (9.6 – 15.8). If a linear frequency dependence of image noise (i.e. sample dominated loss) is assumed, the SNR of ^{35}Cl MRI is expected to be 9.6-fold smaller [3]. A model hypothesizing a domination of electronic losses (e.g. due to the skin effect) leads to an increase in noise with the square root of the frequency [8], which would yield a 15.8-fold difference in SNR performance. In vivo ^{35}Cl and ^{23}Na MRI of the human head could be performed with good image quality (c.f. Fig 2). The reference voltage for ^{35}Cl MRI was 370 V. The reference voltages for ^{23}Na MRI were comparable for both coils (^{35}Cl/ ^{23}Na coil: 303 V; ^1H/ ^{23}Na coil: 290 V). SNR values (brain white matter) of 15 (^{35}Cl MRI), 30 (^{23}Na MRI: ^{35}Cl/ ^{23}Na coil) and 26 (^{23}Na MRI: ^1H/ ^{23}Na coil) were measured.

Table 1: Measured Q values of the different setups. Version 1 contains ^{23}Na traps in the ^{35}Cl resonator. Version 2 contains no traps.

Q_u/Q_l	^{35}Cl	^{23}Na
^{35}Cl/ ^{23}Na (1)	190/109	300/50
^{35}Cl/ ^{23}Na (2)	400/110	400/160
^1H/ ^{23}Na	--	450/50

Table 2: Reference voltages.

coil	^{35}Cl channel	^{23}Na channel
^{35}Cl/ ^{23}Na (1)	397 V	381 V
^{35}Cl/ ^{23}Na (2)	293 V	517 V
^1H/ ^{23}Na	--	326 V

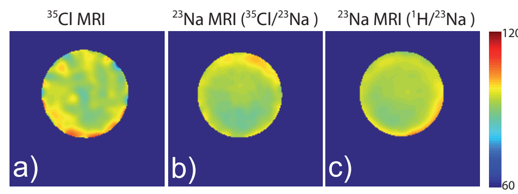

Fig. 1: Transversal B_1 maps of the ^{35}Cl/ ^{23}Na coil (version 1) (a, b). a) ^{35}Cl channel. b) ^{23}Na channel. c) Transversal B_1 map of the ^1H/ ^{23}Na coil. All setups showed good B_1 homogeniety. Average flipangles in the presented transversal slices: a) 93° ± 3°; b) 93° ± 3°; b) 93° ± 2°.

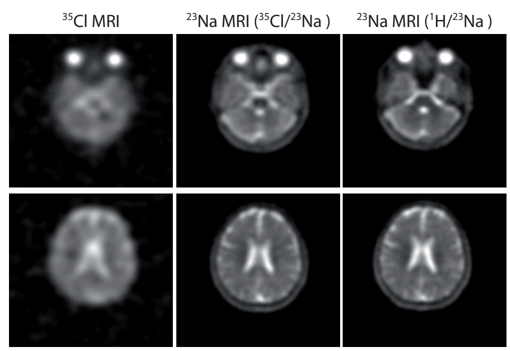

Fig. 2: Transversal slices of 3D ^{35}Cl and ^{23}Na MRI data sets of the healthy human brain. ^{35}Cl MRI could be performed in 10 min with a nominal resolution of $(8\ \text{mm})^3$. Both coils yielded comparable results for ^{23}Na MRI.

Conclusion: By including ^{23}Na traps into the ^{35}Cl resonator, the B_1 efficiency of ^{35}Cl versus ^{23}Na can be controlled. Intermediate steps will be possible by e.g. changing the impedance of the traps. Furthermore, the B_1 optimization can be predicted by simple Q measurements on the workbench. In vivo ^{35}Cl and ^{23}Na MRI of the human head could be performed with good image quality (c.f. Fig 2). Both channels show good B_1 efficiency and SNR performance. This setup allows for combined $^{35}Cl/^{23}Na$ MRI without repositioning of the patient.

References

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