Quantitative mapping of the Cl^-/Na^+ concentration ratio using a double resonant surface coil

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Introduction

^{23}Na magnetic resonance imaging (MRI) has been shown to be an important modality in clinical diagnosis (in general [1] and in particular for the distinction between dead and vital cells after stroke [2].) Recent studies showed that ^{35}Cl can provide additional physiological information, i.e. onset of blood-brain barrier breakdown in focal infarction [3]. However, non-proton MRI suffers from low signal-to-noise ratio (SNR) due to reduced gyromagnetic ratio, short transversal relaxation times and low *in vivo* concentration. Therefore, x-nuclei MRI demands for optimal SNR efficiency. Surface coils enable high local SNR but the inhomogeneous coil sensitivity profile hampers quantification of nuclei concentrations. This work presents a method which uses a double resonant ^{35}Cl-^{23}Na surface coil for quantitative mapping of the Cl^-/Na^+ concentration ratio. The ^{35}Cl and the ^{23}Na signal were measured with the same tuneable loop element. Since the typical sample dimensions are much smaller than $\lambda/10$, we expect approximately the same B_1 profile for ^{35}Cl and ^{23}Na. Therefore, division of the ^{35}Cl images by the ^{23}Na images should yield ratio images which are almost free from the coil profile. Furthermore, using a reference solution with known ion concentration enables calculation of Cl^-/Na^+ concentration ratio maps.

Methods

Sodium and chlorine MRI was done with a double resonant (39.2 MHz / 105.9 MHz) ^{35}Cl-^{23}Na surface coil [4]. Measurements were performed on a 9.4 T Biospec 94/20 USR (Bruker, Germany) small animal system with 740 mT/m gradients. 7 Phantoms were measured. Each phantom consisted of 3 vials: 2 reference vials with 6% NaCl solution (Cl^-/Na^+ concentration ratio 1) and 1 sample vial with 1% NaCl solution and an amount of KCl / NaH_2PO_4 to match a Cl^-/Na^+ concentration ratio of 3, 2.57, 2, 1.78, 1, 0.625 and 0.455, respectively. Imaging was done by a Hanning weighted 3D CSI pulse sequence. ^{23}Na and ^{35}Cl imaging was performed with identical geometrical parameters: FOV = (35×35×30) mm^3, spatial resolution = (1×1×3) mm^3. Other parameters were set to: repetition time = 100 ms, number of repetitions / encoding steps = 30720 (^{23}Na) and 40960 (^{35}Cl), total acquisition time = 51 min (^{23}Na) and 68 min (^{35}Cl), duration RF block pulse (^{23}Na and ^{35}Cl) = 20 µs, duration of the phase encoding gradient = 410 µs (^{23}Na) and 550 µs (^{35}Cl), acquisition delay = 689 µs (^{23}Na) and 549 µs (^{35}Cl). The amplitude of the RF block pulse was determined experimentally in previous scans to match the Ernst angle.

Results & Discussion

Figure 1 shows the ^{23}Na, ^{35}Cl images and the Cl^-/Na^+ concentration ratio map. The color code within the sample is in good agreement with the known ratio of 1.78:1. Figure 2 shows the Cl^-/Na^+ concentration ratio determined from ROIs indicated in Figure 1 and measured on different samples along 8 slices in B_0 direction. The Cl^-/Na^+ concentration ratio shows acceptable consistency over 8 slices for $Cl^-/Na^+ < 2.57:1$. The provided method allows determination of the Cl^-/Na^+ concentration ratio in ionic solutions by means of MRI. Figure 3 shows first results of an ongoing *in vivo* study on rats with a middle cerebral artery (MCA0) stroke. The images show elevated Na^+ and Cl^- concentrations in the right hemisphere of the brain three weeks after occlusion. The normalized divided image indicates a stronger elevation of the Na^+ concentration compared to Cl^- in the area of infarction, indicated by the white arrow. However, further experiments are necessary to ensure statistical significance. In future, the *in vivo* mapping of the Cl^-/Na^+ concentration ratio could be used to gain more insight into ionic regulatory processes.

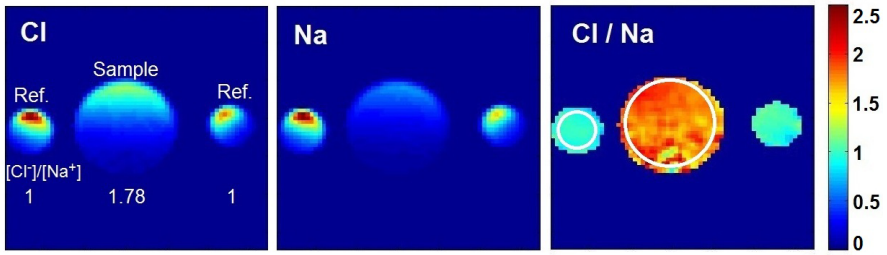

Figure 1: *^{35}Cl, ^{23}Na and divided image of phantoms. Sample vial filled with 1% NaCl and 1% KCl yielding an ion concentration ratio $[Cl^-]/[Na^+]$ of 1.78:1.*

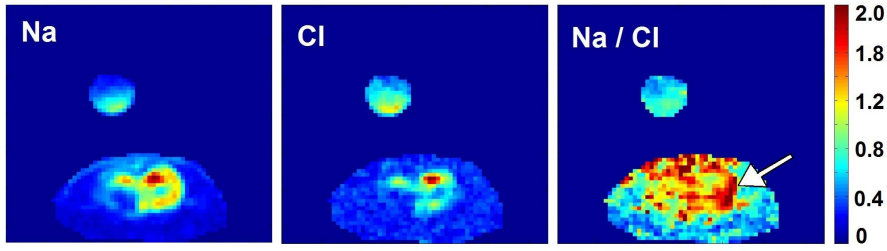

Figure 3: *^{23}Na, ^{35}Cl, and divided image of MCA0 rat 3 weeks after stroke. Reference vial filled with 1% NaCl. White arrow indicates differences in the concentration ratio map.*

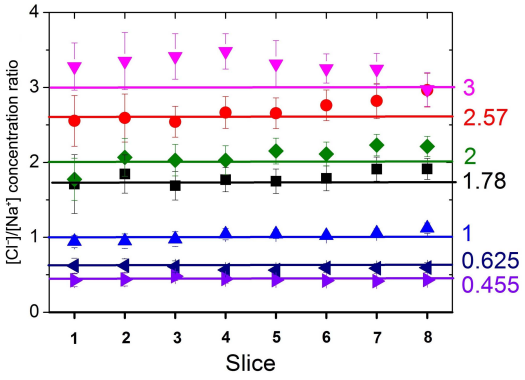

Figure 2: *Known Cl^-/Na^+ concentration ratio of the samples (solid lines) and measured concentration ratios derived from ROIs within the concentration ratio map (compare Fig.1).*

References

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