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

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Introduction

³¹Na 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 ³¹Cl 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 ³¹Cl-³¹Na surface coil for quantitative mapping of the Cl/Na⁺ concentration ratio. The ³¹Cl and the ³¹Na signal were measured with the same tuneable loop element. Since the typical sample dimensions are much smaller than λ/10, we expect approximately the same B₁ profile for ³¹Cl and ³¹Na. Therefore, division of the ³¹Cl images by the ³¹Na 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) ³¹Cl-³¹Na 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 / NaHPO₄ 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. ³¹Na and ³¹Cl imaging was performed with identical geometrical parameters: FOV = (35×35×30) mm³, spatial resolution = (1×1×3) mm³. Other parameters were set to: repetition time = 100 ms, number of repetitions / encoding steps = 30720 (³¹Na) and 40960 (³¹Cl), total acquisition time = 51 min (³¹Na) and 68 min (³¹Cl), duration RF block pulse (³¹Na and ³¹Cl) = 20 μs, duration of the phase encoding gradient = 410 μs (³¹Na) and 550 μs (³¹Cl), acquisition delay = 689 μs (³¹Na) and 549 μs (³¹Cl). The amplitude of the RF block pulse was determined experimentally in previous scans to match the Ernst angle.

Results & Discussion

Figure 1 shows the ³¹Cl, ³¹Na 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 B₀ 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.

References