In-vivo ^{37}Cl Magnetic Resonance Imaging at 7 Tesla

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INTRODUCTION

Chloride (Cl^-) is the most abundant anion in the human body and plays a significant role in cellular processes. Cl^- exhibits two naturally occurring NMR sensitive isotopes with natural abundances of 76% and 24%, for ^{35}Cl and ^{37}Cl, respectively. At 7 Tesla the resonance frequencies are 29.1 MHZ (^{35}Cl) and 24.2 MHz (^{37}Cl). Thus, ^{35}Cl has a higher NMR sensitivity than ^{37}Cl and was preferred for MRI [1- 3]. However, ^{35}Cl exhibits fast transverse relaxation times that complicate quantitative measurements. In part this is compensated by the lower quadrupol interaction leading to longer relaxation times of ^{37}Cl. ^{37}Cl exhibits a smaller electrical quadrupole moment than ^{35}Cl [4]. Thus, 1.5 to 1.6-fold longer T_{2f} relaxation times are expected [5]. The aim of this work was to quantify ^{37}Cl relaxation times and to evaluate the feasibility of in-vivo ^{37}Cl MRI on a 7 Tesla whole-body MRI system.

METHODS

A frequency conversion scheme similar to [6] was used. All measurements were conducted on a 7 Tesla whole-body MRI system (Magnetom 7T, Siemens Healthcare, Erlangen, Germany). A custom made solenoid coil was designed and built (length= 8 cm, diameter= 7 cm, 3 turns of copper tape, width=12 mm).

Phantom measurements: Phantoms containing 0.9 % sodium chloride solution with different agar concentration (0%, 1%, 3%, 4%) were used for relaxation time measurements. Longitudinal (T_1) and transverse relaxation times (T_2^*) were determined with a density adapted 3D radial sequence (DA-3DPR) [7]. For the T_2^* measurements 4 multiecho sequences with 8 echoes each (TE = 0.3... 250 ms) were used (TR= 300 ms, TA=1500 s, T_{RO}= 5 ms). The 32 echo times TE varied for the different phantoms because a decrease of the relaxation time was expected with increasing agar concentration. For the T_1 measurement an Inversion Recovery sequence was used with 25 different TIs between 1 and 290 ms. To estimate the relaxation times monoexponential fitting (pure sodium chloride solution) and a biexponential model were chosen with a long and a short component of the relaxation time. Additionally a noise term was considered ($S = \sqrt{A^2\left(0.6e^{-\frac{t}{T2s}} + 0.4e^{-\frac{t}{T2l}}\right)^2 + N^2}$ and $S = \sqrt{A^2(1 - 2\left(0.2e^{-\frac{t}{T1s}} + 0.8e^{-\frac{t}{T1l}}\right))^2 + N^2}$). In figure1 the results are shown and compared to a study of ^{35}Cl with the same phantoms [8].

In-vivo measurements: A narcotized rat was imaged using a DA-3DPR sequence. For comparison ^{35}Cl was co-registered with the setup. The imaging parameters were TR= 55 ms, TE= 0.3ms, α= 90° and the image was Hamming filtered. A nominal resolution of (5 mm)³ was achieved within 45:50 min acquisition time for the ^{37}Cl measurement and (4 mm)³ within 18:20 min for ^{35}Cl. On top of the rat's head two reference phantoms with 6 ml NaCl solution, one with 0.9 % and one with 0.3% NaCl were placed.

RESULTS

In all cases the measured relaxation times of ^{37}Cl were longer than the ones of ^{35}Cl (Fig.1). Increasing the agar concentration the time constant decreased. For ^{37}Cl the fitting results give T_1= 48.7±0.7 ms and T_2^*= 46.6±0.7 ms for pure NaCl solution. The lowest values were determined for an agar concentration of 4% with T_{2l}^*= 7.2 ±0.2 ms, T_{2s}^*= 1.6±0.1 ms and T_{1l}= 19.4±0.6 ms and T_{1s}= 2.7±0.4 ms.

The in-vivo image of a rat showed that the signal of the rat relative to the reference phantom is higher using ^{37}Cl measurement compared to ^{35}Cl.

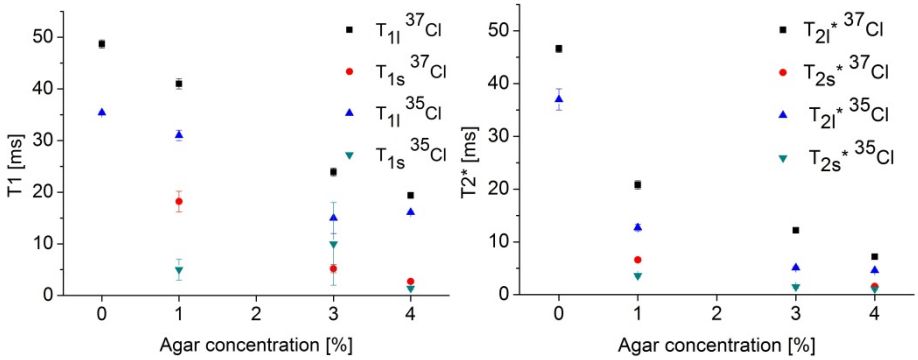
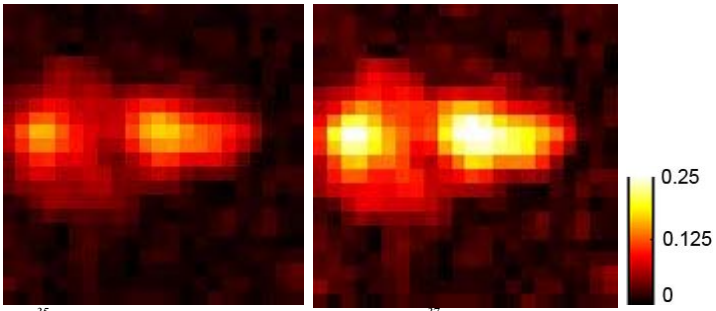


Fig.1 Fitting results of the relaxation times for phantoms with 0.9 % NaCl solution and different agar concentrations. a) longitudinal relaxation of ^{37}Cl in comparison with ^{35}Cl b) T_2^* of ^{37}Cl and ^{35}Cl

DISCUSSION

To the best of our knowledge this study shows the first ^{37}Cl in-vivo data. The measured relaxation times in the phantom study were lower than expected in theory. Especially an evaluation of T_2 could eliminate this ambiguity. It was shown that ^{37}Cl in-vivo imaging is possible on a clinical 7T MRI system. The longer relaxation times of ^{37}Cl should enable a more reliable quantification of in-vivo concentration at the expense of slightly reduced spatial resolution.



a) ^{35}Cl image with a resoultion of (4 mm)² b) ^{37}Cl image with a resolution of (5mm)²

Fig.2 In-vivo image of a rat: FOV = (110 mm)³, coronary slice with the head and part of the body. Normalization was performed to the reference tube containing 0.9% NaCl. The ^{35}Cl MRI data set was multiplied by a factor of 1.15 to compensate the difference in the ^{35}Cl and ^{37}Cl relaxation behavior of the reference tubes. Nevertheless, the ^{37}Cl images showed a higher normalized signal intensity which can be attributed to the longer T_2^* relaxation times of ^{37}Cl.

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