In vivo ^{37}Cl MRI of Human Calf Muscle at 7T

Judith Schork[1], Anna Kollefrath[1], Manuela B. Rösler[1], Reiner Umathum[1], and Armin M. Nagel[1]
[1]*Medical Physics in Radiology, German Cancer Research Center (DKFZ), Heidelberg, Germany*

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

Purpose: Chloride (Cl^-) plays an important role in several physiological processes such as the excitation and inhibition of cells [1]. There are two naturally occurring isotopes of chlorine that are NMR sensitive. ^{35}Cl has a higher natural abundance (76%) as well as a higher Larmor frequency (29.1 MHz at 7 T) than ^{37}Cl (24%, 24.2 MHz). Thus, ^{35}Cl exhibits higher NMR sensitivity than ^{37}Cl and therefore ^{35}Cl has been preferred for MRI [2-4]. However, due to the very short transverse relaxation times, quantitative ^{35}Cl MRI is challenging. ^{37}Cl exhibits 1.27-fold lower electrical quadrupole moment than ^{35}Cl [5] resulting in 1.5- to 1.6-fold longer T_{2f}^* for ^{37}Cl [6]. The slow component of the transverse relaxation time (T_{2s}^*) should increase by a factor of 1.1 to 1.6. The feasibility of ^{37}Cl MRI on a clinical 7T MR system has been demonstrated recently [7]. In this work, we present the first in vivo ^{37}Cl images of a human calf muscle. Additionally, in vivo transverse relaxation times of ^{35}Cl and ^{37}Cl were compared.

Methods: ^{37}Cl measurements were conducted on a 7T whole body MR system (MAGNETOM 7 T, Siemens AG, Healthcare Sector, Erlangen, Germany) using a custom made quadrature birdcage coil (inner diameter : 18 cm; leg length: 21.3 cm). To compare relaxation times, ^{35}Cl MRI was performed using a dual tuned (^{1}H/^{35}Cl), quadrature birdcage coil (inner coil diameter: 22 cm) (QED, Mayfield Village, Ohio, USA). All ^{35}Cl and ^{37}Cl MRI sequences were based upon a density-adapted 3D radial projection reconstruction pulse sequence (DA-3DPR) [8]. In phantom studies T_1 and T_2 relaxation times of ^{35}Cl and ^{37}Cl were measured using global inversion recovery and global spin echo sequences, respectively. For in vivo imaging the calf muscle of a healthy subject (male, 63 years) was examined. To determine the transverse (T_2^*) relaxation times in vivo the following acquisition parameters were used:

T_2^* measurements: 7 multi-echo sequences with 3 echos each (TE_1 = 0.35, 0.55, 0.75, 1.00, 1.25, 1.50, 2.75 ms; TE_2 = 4, 4.6, 5.2, 6.0, 6.6, 7.3, 8 ms; TE_3 = 8, 9, 10, 11, 12, 13, 14 ms; α = 90°; TR = 80 ms; T_{RO} = 2.5 ms; T_{AQ} = 6:40 min; 5000 projections; Hamming filtering)

The transverse relaxation time was calculated by using a bi-exponential model

$$S(TE) = \sqrt{M_0^2 \left(A\, e^{-\frac{TE}{T_{2f}^*}} + (1-A)\, e^{-\frac{TE}{T_{2s}^*}} \right)^2 + N^2}$$, where A is the amplitude of the fast component.

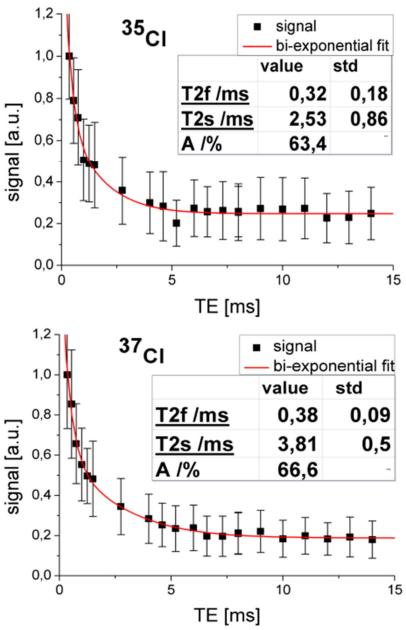

Fig. 1: T_2^* relaxation times of ^{35}Cl and ^{37}Cl in vivo, bi-exponentially fitted

Results: The data of the phantom studies are given in Tab. 1. These results show longer relaxation times for ^{37}Cl than for ^{35}Cl. As shown by the outcome values, the transverse relaxation times of ^{37}Cl in the in vivo measurements are a longer than those of ^{35}Cl. In the phantom studies T_1 values of ^{35}Cl and ^{37}Cl differ by about a factor of 1.4 to 1.6. The transverse relaxation times exhibit ratios of 0.9 to 1.4 and 1.2 to 1.6 for the fast and the slow components, respectively. The measured in vivo T_{2f}^* values of ^{37}Cl are a factor of 1.2 longer than those of ^{35}Cl. T_{2s}^* of the two isotopes differ from each other about a factor of 1.5. Moreover, the amplitude (A) of the short component of the transverse relaxation time is close to the theoretically expected value (60%).

Discussion and Conclusion: In this work, ^{37}Cl images of a human calf muscle were acquired for the first time. The increase of the relaxation times is close to theoretically expected one. Slight deviations from this behavior occur in particular for the fast component of the transverse relaxation time. This is most likely due to systematic errors caused by the extremely short relaxation times. Due to its longer relaxation times, ^{37}Cl MRI should enable a more reliable quantification of in vivo Cl^- concentrations at the expense of reduced spatial resolution.

Tab. 1: Results of the phantom studies measured with global sequences; T_1 and T_2 relaxation times of ^{35}Cl and ^{37}Cl in 0.9% sodium chloride solution containing different agarose gel concentrations

Phantom studies	0% Agarose	1% Agarose	2% Agarose	3% Agarose	4% Agarose	5% Agarose
T_1 ^{35}Cl /ms	33.76±0.05	20.72±0.02	15.1±0.02	11.92±0.02	9.95±0.02	8.62±0.03
T_{2f} ^{35}Cl /ms	--	3.28±0.07	1.90±0.05	2.0±0.1	2.08±0.06	2.02±0.08
T_{2s} ^{35}Cl /ms	34.54±0.06	15.2±0.2	11.6±0.1	9.3±0.2	7.8±0.3	6.9±0.3
A (^{35}Cl) /%		61.0	72.0	65.4	64.0	64.6
T_1 ^{37}Cl /ms	54.19±0.09	32.01±0.04	22.82±0.04	17.56±0.04	14.48±0.04	12.36±0.05
T_{2f} ^{37}Cl /ms	-	4.67 ± 0.12	2.44±0.08	2.30±0.11	1.95±0.14	2.30±0.18
T_{2s} ^{37}Cl /ms	53.5±0.3	23.18 ± 0.53	15.03±0.28	12.05±0.34	9.82±0.37	9.28±0.60
A (^{37}Cl) /%		65.1	70.3	69.3	69.1	71.9

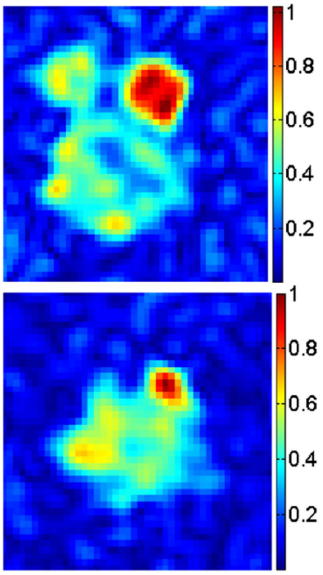

Fig. 2: Selected transversal slices of 3D ^{35}Cl (upper image) and ^{37}Cl (lower image) data sets of a human calf muscle with NaCl phantoms.

References: [1] T. Jentsch et al., Physiol. Rev. 2002. [2] A. Nagel et al., Radiology (2014). [3] S.Kirsch et al., NMR Biomed (2010). [4] V. Schepkin et al., Magn Reson Mater Phy (2013). [5] K. Harris et al., Magn. Reson. Chem. (2002). [6] G. Jaccard et al.; J Chem Phys (1986). [7] A. Kollefrath et al., Intl. Soc. Mag. Reson. Med. (2014). [8] A. Nagel et al., Magn. Reson. Med. (2009).