Sodium MRI with Triple Quantum Filter and Inversion Recovery at 7T

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Introduction: Sodium MRI has already been applied to the study of brain, heart and musculoskeletal diseases[1]. In biological tissues, sodium has a bi-compartmental distribution: extra-cellular and intracellular with the concentrations being $[^{23}Na]_{ext} \approx 140$ mmol/L and $[^{23}Na]_{int} \approx 15$ mmol/L respectively. The concentration gradient is maintained by the Na-K pump which transports the ions through the cell membrane. In pathologies, the concentration gradient between intra- and extra-cellular is altered and therefore an increase in sodium signal is often observed, as for example in brain tumors or ischemia[1]. The most relevant information, however, comes from the intracellular sodium because it reflects the ability of the cell to pump out sodium ions, whereas $[^{23}Na]_{ext}$ stays constant due to the perfusion of the tissue. Two main approaches have been proposed to isolate the NMR signal from intracellular sodium: inversion recovery (IR) MRI[2] and triple quantum filter (TQF)[3]. As the longitudinal relaxation time T1 of the extracellular sodium may be significantly longer than the T1 of the intracellular sodium, IR can be used to eliminate the signal contribution from either environment. The TQF technique uses coherence transfer schemes to generate a signal that is related to the presence of bi-exponential T2 relaxation in solids and biological tissues. The goal of the present work is to study the feasibility of IR and TQF ^{23}Na MRI at 7T on phantoms simulating biological tissues, knowing that these techniques are very sensitive to B_0 inhomogeneities and require short pulses with high amplitudes.

Material and methods: The study was performed on a 7T Whole Body Scanner (Siemens Medical Solutions, Erlangen, Germany), with a single tuned ^{23}Na head coil (XLR Imaging Inc., London, Ontario, Canada). The images were acquired using a 3D radial sequence[4] with TQF and IR preparation, schematically presented in Figure 1. The sequence parameters were: TE 0.05 ms, 384 radial views, Matrix 32×32, FOV 320×320 mm^2, BW 130 Hz/pixel, Resolution 10×10×10 mm^3.The parameters for TQF were: flip angle (FA) $\theta_1 = \theta_2 = \theta_3 = 90°$, the preparation time $\tau = 8$ ms, the evolution time $\delta = 120$ µs, 6 steps of phase cycling[3] for φ_1, φ_2 and φ_3, the receiver phase alternates between 0º and 180º, TR 300 ms, 18 averages, TA 34:35 min. The IR parameters were: FA $\theta_1 = 0°$, $\theta_2 = 180°$, $\theta_3 = 90°$, TI corresponds to different values of δ, 4 steps of phase cycling with $\varphi_2 = 0°$, 180º, 90º and 270º, $\varphi_3 = 0°$, receiver phase = 0º, TR 260 ms, 4 averages, TA 6:41 min. The pulses are non-selective with constant amplitude over 2ms.

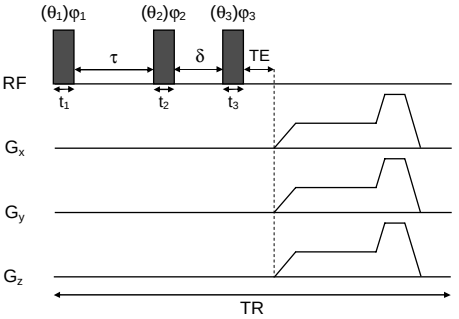

Figure 1. 3D Radial sequence with filters.

Results and discussion: The sodium images with IR and TQF are shown in Figure 2. For TQF, only the signal from the 4% agar gel is visible, since TQF signal arises only from bound sodium nuclei with slow motion compared to the Larmor frequency (78.9 MHz at 7T). The SNR is 13 for 4% agar-140 mM Na, 10 for 2%-100 mM and 6 for 1%-50 mM. It can also be seen that free and bound ^{23}Na nuclei can be differentiated because of their different T1 relaxation by IR imaging : in the isotropic solution, as CSF, the measured sodium T1 ≈ 46 ms, and in a more solid environment as in 4% agar gels, T1 ≈ 28 ms. Intermediate states of the nuclei can also been differentiated by the same IR technique (data not shown) : for 2% agar gel, T1 ≈ 35 ms, for 1% agar gel, T1 ≈ 40 ms. In the IR experiment, contrast is achieved based on the differences in the overall T1 relaxation rates in different compartments, whereas TQF contrast is based on the bi-exponential T2 relaxation behavior of the ^{23}Na nuclei and thus gives different information about the sodium environment.

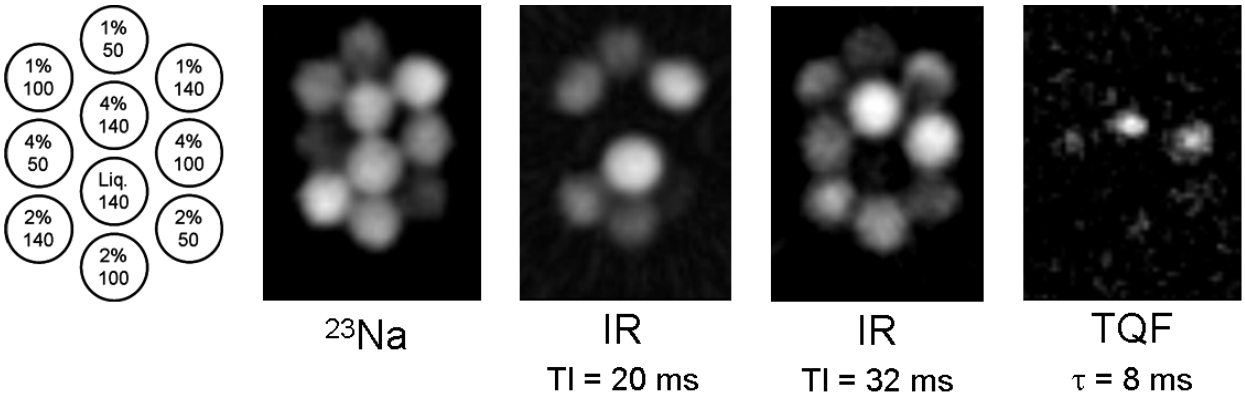

Figure 2. Sodium MRI at 7T with IR and TQF on gels phantoms (gels with 1%, 2% and 4% Agar contents and 50, 100 and 140 mM of ^{23}Na concentrations) and 1 liquid + 140 mM ^{23}Na phantom.

Conclusion: This study demonstrates the feasibility of TQF and IR sodium MRI at 7T in differentiating mobile vs. less mobile ^{23}Na nuclei in phantoms. Sodium in extra- vs. intra-cellular compartments in biological tissues will contribute with different weights to the TQF and IR signals based on their mobility. The combination of TQF and IR can give complementary information about the sodium environment and allow for a better differentiation between these compartments. The presented studies form the groundwork for implementing TQF and IR ^{23}Na MRI for the human brain *in vivo* at 7T in order to assess the intracellular sodium concentration, with the goal of localizing pathologies.

References: 1. New York Academy of Sciences, eBriefing on Sodium MRI (http://www.nyas.org/ebriefreps/splash.asp?intebriefID=566); **2.** Stobbe R *et al.*, Magn Reson Med 2005, 54, 1305-1310; **3.** Hancu I *et al*., Magn Reson Med 1999, 42, 1146-1154; **4.** Nielles-Vallespin S *et al*, Magn Reson Med 2007, 57, 74-81;

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