In vivo high-resolution imaging and T1 mapping of brain sodium at 4T

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Introduction
Despite the fact that sodium is the second most abundant NMR-active nucleus in the human tissue, that many disorders involve changes in the sodium concentration, and that several examples of sodium imaging have been demonstrated in the last two decades, including cerebral studies at fields as low as 1.5T [1], sodium imaging is still not widespread. A likely cause for this is that the vast majority of the existing studies have been using specially developed sequences, not provided by the manufacturers, that the low sensitivity of Na is usually compensated by using large voxels giving little anatomical detail, and that sodium imaging is associated with expensive hardware requirements such as dedicated RF coils, high fields and/or gradient strengths. However, with increasing availability of 7T and higher field systems worldwide aimed at clinical research, it is to be expected that Na imaging will be soon integrated in the study of different pathologies. The usefulness of a simple gradient echo sequence to provide quantitative information about Na properties in normal and diseased tissue has been suggested long ago [2]. We make use of such a sequence to demonstrate sodium imaging on the brain with resolution high enough to provide visualisation of anatomical detail. In addition, and also based on gradient echo acquisitions, a simple method for T1 mapping is discussed.

Materials and methods
Measurements were performed on a 4T whole-body scanner (MedSpec, Bruker/Siemens) equipped with a 40mT/m gradient coil (250µs rise time). A double-tuned $^{1}H/^{23}Na$ birdcage coil (Rapid Biomedical) was used for RF transmission and reception. B0 shimming was performed using the ^{1}H channel. The voltage V_{ref} required by the ^{23}Na channel to produce a 90deg pulse was determined by monitoring the changes with increasing V of the signal produced by a pulse-acquire sequence, independently in each measurement session. A gradient echo sequence was used, which also allowed for multiple-echo acquisition. For T1 mapping, two gradient-echo acquisitions with different TR and flip angle were used, in a manner similar to that described in [3] for protons. The imaging parameters included: TR1,2=25,30ms, alpha1,2=20,90deg, pulse length 500µs, TE_1=4.2ms, FOV= 256x204x137 mm^3, voxel size $(3.12mm)^3$, matrix size = 80x64x44, 5/8 Fourier in phase and slab encoding, asymmetric echo (25% asymmetry), BW=80Hz/pixel, 6 avgs. A 29 year old female volunteer was studied. A total of 15 measurements were averaged, resulting in a measurement time of ~ 45 min/parameter set. Due to the long combind acquisition time for the two parameter sets required for T1 mapping, the scans have been divided between two different sessions. The volume obtained after averaging of all scans from the first session was coregistered to the one obtained in the second session. A 50ml probe filled with isotonic saline was placed in the FOV, to provide a measure of relative sodium concentration in tissue. In addition to the imaging protocol, the longitudinal relaxation time was measured for the whole system by a series of sequences consisting of pulse-acquire following inversion with different inversion delays TI. The parameters of the two GRE acquisitions were optimised for the measurement of T1 times in the range 30-50ms [4] using Monte Carlo simulations based on the Ernst equation with the addition of white noise.

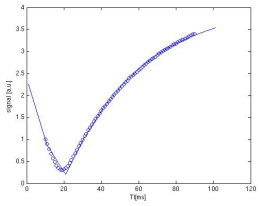

Fig1: spectroscopic T1 measurement

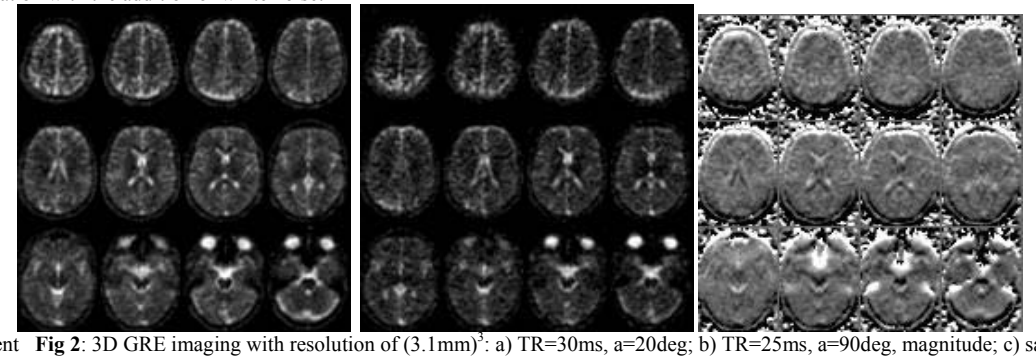

Fig 2: 3D GRE imaging with resolution of $(3.1mm)^3$: a) TR=30ms, a=20deg; b) TR=25ms, a=90deg, magnitude; c) same, phase

Results and discussion The spectroscopic data obtained on the brain and small saline probe together were reasonably well described by monoexponential inversion recovery with T_1=41ms (Fig 1). The value compares well with the value of 36 ms reported at 4.7T, also obtained by monoexponential fitting [4]. It is well-known that sodium in brain tissue displays biexponential T1 in addition to T2 relaxation [5], but the fast component (20% of the total) cannot be fitted reliably in most applications and was not considered here. The results of the Monte Carlo simulation delivered clear minima for the combination TR1,2=30,25ms, alpha1,2=20,90deg. A precision of better than 15% SD is predicted for the T1 calculation with these parameters, as well as a systematic deviation from the correct value of < 10% for SNR values of 5 or more. T1 mapping with 2-point method is very SNR-sensitive. We have therefore averaged the data using a sliding window algorithm, with 2, 3 or 4 voxels averaged in each dimension, and repeated the calculation of the maps. The histograms showing the ensuing T1 distribution over the whole brain are shown in Fig.3.

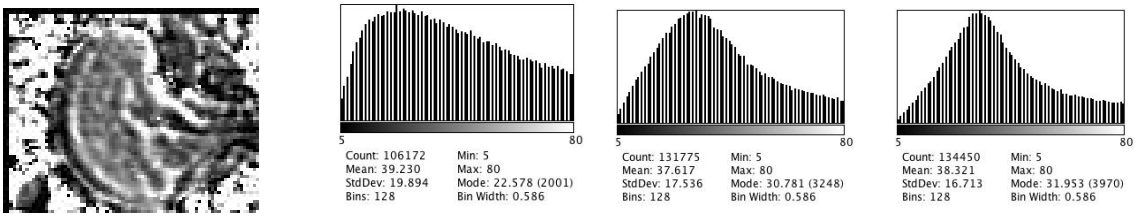

Fig. 3

Conclusions High-resolution imaging is not beneficial for applications suffering from low SNR [Haacke]. However, the visualisation of anatomy is an important requirement for clinical applications, and the reduction of partial volume effects is beneficial for quantitative studies. Based on images with 3.1mm resolution acquired on a 4T whole-body scanner with two sets of parameters, T1 mapping can be preformed as well. Since the SNR of sodium is expected to increase more than linearly with the field strength, this SNR-sensitive method is expected to have extensive applicability at the highest fields available for human imaging (7T, 9.4T).

References [1] Hilal SK et al, J Comput Assist Tomogr. 9: 1-7 (1985); [2] Granot J, J Magn Reson 68: 575-581 (1986); [3] Deoni S et al., Magn Reson Med 49: 515-26 (2003); [4] Stobbe R and Beaulieu C, Magn Reson Med 59: 345-355 (2008); [5] Woessner DE. Concepts Magn Res 2001;13:294–325; [6] Haacke M et al., Wiley-Blackwell (1999).