Quantitative Sodium MRI with Fluid Suppression in the Knee Joint at 3T and 7T

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Introduction: Osteoarthritis (OA) is a degenerative disease associated with a loss of proteoglycans (PG) in articular cartilage. Sodium concentration is directly linked to the PG content in cartilage, therefore it is expected that quantitative sodium MRI can be used as an indicator of early OA [1]. However, sodium is present in the knee joint in 2 pools: slow motion sodium in cartilage and fast motion sodium in the synovial fluid. Suppressing the fluid sodium in sodium MRI can be done using an inversion recovery (IR) method [2] based on the T1 difference of the sodium ions in the 2 pools and was demonstrated in vivo in cartilage at 7T recently [3]. In this preliminary study, as few 7T scanners are available to date, we show that this method can also be translated to 3T with good sensitivity by comparing the data obtained on the same healthy volunteers at 3T and 7T.
A*bbreviations*: F: femur, T: tibia, PAT: patellar, MED: FT medial, LAT: FT lateral, CON: F condyle, [^{23}Na]: sodium concentration.

Materials and Methods: Sodium images were acquired on a 7T whole-body and a 3T Tim Trio Siemens scanners using 2 single tuned quadrature birdcage RF knee coils (Rapid MR International for 7T, custom built for 3T), tuned to 78.6 MHz and 32.6 MHz respectively. The data were acquired with a 3D UTE radial sequence written with SequenceTree [4] and compiled with the Siemens IDEA environment. Acquisition parameters were, at 3T: 15000 projections, TR 80 ms, RF pulse 80°/0.5 ms, and at 7T: 10000 projections, TR 100 ms, RF pulse 90°/0.5 ms. FOV was 200×200×200 mm^3. For fluid suppression, an IR preparation was added prior to the readout RF pulse. 2 inversion pulses were tested: a rectangular pulse of 180°/1 ms (IR RECT, with TI 27 ms at 7T and 25 ms at 3T) and an adiabatic WURST pulse [5] of 250Hz/10 ms at 3T, and 240Hz/10 ms at 7T (IR WURST, with TI 24 ms at 7T and 22 ms at 3T). Due to SAR limitations, the IR WURST sequence at 7T was used with a TR of 140 ms. Images were reconstructed offline in Matlab with a Non-Uniform Fast Fourier Transform (NUFFT) algorithm [6]. In order to avoid partial volume effects between 3T and 7T in the [^{23}Na] measurements, all the images were reconstructed as 100×100×100 matrices with a nominal resolution of 2 mm. 4 asymptomatic healthy volunteers (2 females, 2 males) were scanned (average age: 26.5±1.73 years). 5 calibration phantoms of Agar 4% with [NaCl] = 100, 150, 200, 250, 300 mM were placed within the FOV. Sodium maps were calculated from a linear regression of the signal of the calibration tubes with correction for both the relaxation times of the gels and cartilage and for the extracellular volume of cartilage (75%) [3]. Average [^{23}Na] were then measured in 4 regions of the cartilage, on 4 consecutives slices for each volunteer.

Table 1. [^{23}Na] in mM in articular cartilage at 3T and 7T (see text for abbreviations).

	3D Radial		IR RECT		IR WURST	
	3T	7T	3T	7T	3T	7T
PAT	**195** ± 50	**226** ± 81	**261** ± 73	**283** ± 82	**267** ± 72	**277** ± 70
MED	**150** ± 39	**193** ± 71	**228** ± 30	**255** ± 58	**214** ± 45	**260** ± 40
LAT	**126** ± 28	**176** ± 65	**178** ± 46	**225** ± 88	**167** ± 57	**213** ± 55
CON	**141** ± 46	**186** ± 70	**217** ± 51	**232** ± 69	**194** ± 45	**220** ± 52
Mean	**152** ± 48	**195** ± 70	**221** ± 60	**249** ± 77	**211** ± 66	**242** ± 60

Results: SNR in cartilage at 3T was ~20 with 3D radial and ~10 with fluid suppression. SNR at 7T was determined as double of the SNR at 3T. Mean [^{23}Na] in different regions of the cartilage and their mean values over the 4 regions are given in Table 1. In general, the measurements from 3D radial (without fluid suppression) were less than the ones with fluid suppression. [^{23}Na] Measurements at 3T were also lower than at 7T in all the regions. Good agreement in [^{23}Na] can be seen between IR RECT and IR WURST within the same field. Fig 1 shows [^{23}Na] maps in the patellar cartilage at 3T and 7T. Note the better fluid suppression of the PBS signal with the WURST pulse compared to the rectangular pulse shown on the images at 7T. Fig 2 shows a Bland-Altman plot [7] of the sodium concentrations measured from each sequence at 3T and 7T. Each point corresponds to the mean [^{23}Na] value of one measurement at 3T and 7T for a specific sequence and a specific slice. From this plot, we can see that on average, the measurements at 3T are ~30 mM lower than at 7T, but still within the range of the data standard deviation (40 mM).

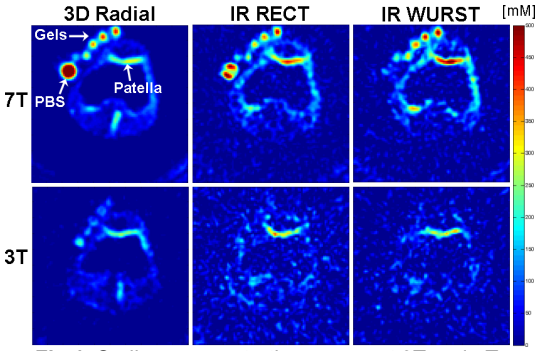

Fig 1. Sodium concentrations maps at 3T and 7T.

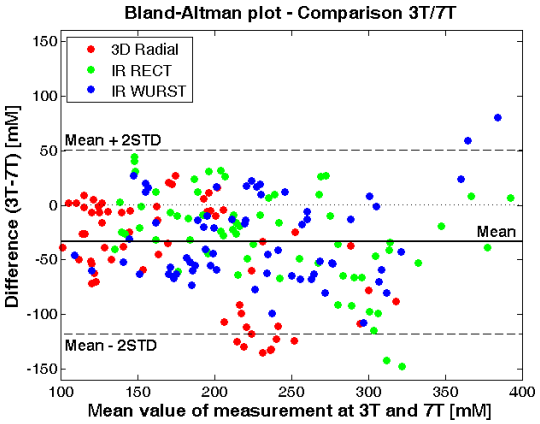

Fig 2. Bland-Altman plot: comparison of the sodium concentrations measured with the 3D radial, IR RECT and IR WURST sequences at 3T and 7T.

Discussion: The mean [^{23}Na] is lower than the usual values seen in the literature (~240-300 mM in healthy cartilage). This is most likely due to the small number of volunteers studied to date and because one of the volunteers had very low [^{23}Na], in both measurements at 3T and 7T, leading to a large decrease in mean [^{23}Na] and increase in the standard deviations. More volunteers are therefore needed to improve the accuracy of this method. Nevertheless, similar measurements of [^{23}Na] were obtained at 3T and 7T, and the purpose of this preliminary study is to first compare the method at these fields. A paired t-test was applied to all the data and no significant difference ($p>0.05$) was observed between results obtained with IR RECT and IR WURST within the same field, or between 3T and 7T results A significant difference was observed between 3D Radial at 3T and all the other sequences and both fields.

Conclusion: This preliminary work demonstrates the feasibility of quantitative sodium MRI with fluid suppression by IR at 3T. Despite low SNR, the 3T data show good agreement with 7T data, even though the calculated [^{23}Na] is overall slightly lower (-30 mM). More volunteers/OA patients are scheduled to test the IR sequences at both fields and to check the accuracy and statistical significance of the results between the 2 fields.

References: 1. Borthakur A et al., NMR Biomed, 19(7), 2006. **2**. Stobbe R et al., MRM 54(5), 2005. **3**. Madelin G et al., JMR 207, 2010. **4**. Magland J et al., Proc. ISMRM 2006. **5**. Kupce E et al., JMR A115, 1995. **6**. Greengard L et al., SIAM 46(3), 2004. **7**. Bland JM et al., The Lancet 327, 1986.
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