Repeatability and Reproducibility of Quantitative Sodium MRI of Cartilage In Vivo at 3T and 7T

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Introduction. Osteoarthritis (OA) is a degenerative disease of articular cartilage associated with a loss of glycosaminoglycans (GAG). Quantitative sodium MRI is highly specific to the GAG content and could be used to assess the biochemical degradation of cartilage in early stages of OA [1]. However, the reproducibility and repeatability of this technique are not well documented. The aim of this study is therefore to assess the reliability of sodium MRI for sodium quantification in cartilage in vivo using intra-day and inter-day acquisitions at 3T and 7T, with a 3D radial sequence, with and without fluid suppression. Fluid suppression was obtained by adiabatic inversion recovery (IR WURST [2]), and is expected to improve the sensitivity of the method to GAG content. Definitions of repeatability and reproducibility: Closeness of the agreement between independent results obtained with the same method on identical test material under the *same* conditions (repeatability) or under *different* conditions (reproducibility) of measurements. They are measured as coefficients of variation (CV, in %). Goal of the study. (**1**) To measure the repeatability of sodium quantification: at each of 3T and 7T (*intra*-magnet), with each of Radial 3D and IR WURST (*intra*-sequence). (**2**) To measure the reproducibility of sodium quantification: at 3T vs. 7T (*inter*-magnet), with Radial 3D vs. IR WURST (*inter*-sequence). Repeatability and reproducibility were each assessed in terms of acquisitions on the same day (*intra*-day) and over different days (*inter*-day).

Materials and Methods. Sodium images were acquired on 6 asymptomatic volunteers (mean age: 37±12 years) following the protocol described in Fig. 1, at 3T and 7T (Siemens). For Radial 3D, at 3T: 15,000 projections, TE 0.15ms, TR 80ms, FA 90°, TA 20min; at 7T: 10,000 projections, TE 0.15ms, TR 100ms, FA 90°, TA 17min. For IR WURST, at 3T: same as Radial 3D + WURST [3] inversion pulse 240Hz/10ms, TI 22 ms, TA 20 min; at 7T: same as Radial 3D except TR 140 ms, WURST pulse 240Hz/10ms, TI 24 ms, TA 25 min. FOV was 200mm, resolution was 2mm isotropic. Images were reconstructed in Matlab with a NUFFT algorithm [2,4,5]. Sodium quantification: [^{23}Na] maps were calculated by linear regression using calibration phantoms of known sodium content and relaxation times (150, 200,250, 300 mM) [2]. Mean and standard deviation (SD) of [^{23}Na] were measured in 4 regions in the cartilage: patellar (PAT), femoro-tibial medial (MED), femoro-tibial lateral (LAT) and medial posterior femoral condyle (CON). CVNa (%) was calculated as 100×SD/Mean [^{23}Na]. Statistical analysis: Mixed model analysis of variance (ANOVA) was used to assess and compare sequences in terms of mean and SD [^{23}Na] observed for each region in cartilage at each field strength. Root mean square (RMS) of CVNa was calculated for each region for each magnet-sequence combination. The CV of intra- and inter-day component of the overall variance of the mean [^{23}Na] was also computed for each region and each magnet-sequence combination (intraCVNa, interCVNa). These later CVs correspond to the statistical variation of the results over many measurements (on same day or over different days).

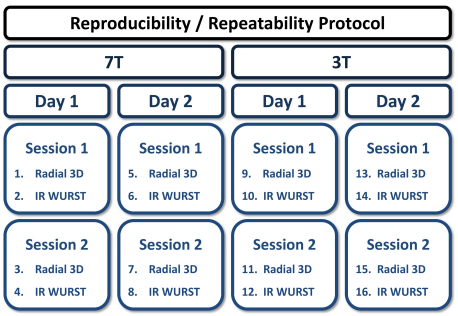

Figure 1. Acquisition protocol.

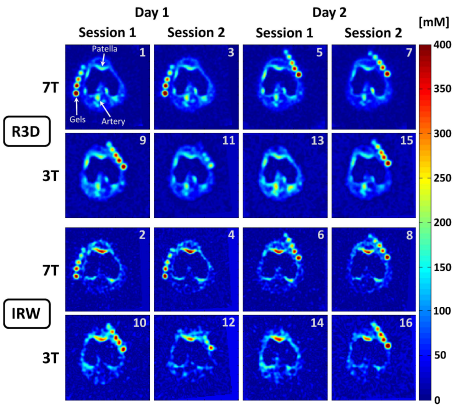

Figure 2. Co-registered sodium maps.

Results. Examples of images from a volunteer are shown in Fig 2. Image numbers correspond to the acquisitions from Fig. 1. RMS of CVNa are given in Table 1. All the intraCVNa and interCVNa over all sequences, over all magnets, and also over all the data, all lie in the small range 5.2-6.8 %. Goal of the study: (**1**) Repeatability of sodium quantification: (**1a**) intra-magnet, at 3T: RMS CVNa ~10%, and at 7T: RMS CVNa ~11.5%; (**1b**) intra-sequence, with Radial 3D: RMS CVNa ~10%, and with IR WURST: RMS CVNa ~11.7%; (**1c**) over different acquisitions on the same day: no significant intra-day difference of the CVNa ($p>0.05$); (**1d**) over different days of acquisition: no significant inter-day difference of the CVNa ($p>0.05$). (**2**) Reproducibility of sodium quantification: (**2a**) at 3T vs. 7T: no significant inter-magnet difference of CVNa ($p>0.05$) but significant difference for mean [Na+] ($p<0.0001$); (**2b**) with Radial 3D vs. IR WURST: no significant inter-sequence difference of the CVNa ($p>0.05$) but significant difference for mean [Na+] ($p<0.0001$).

Discussion-Conclusion. The RMS of CVNa over all magnets and sequence lie in the range 7.5-13.6%. All the intraCVNa and interCVNa from different combinations of magnet-sequences show consistency regardless of the acquisition (~6%). The repeatability and reproducibility CV of [^{23}Na] measured using the proposed quantitative sodium MRI techniques compare therefore favorably with the CV of other proton-based MRI techniques (2-8% for cartilage thickness [6], 5-13% for dGEMRIC [7], 6-29% for T2 map [8], 7-19% for T1ρ map [9]).

Table 1: RMS of CVNa (in %)

	Radial 3D		IR WURST	
	3T	7T	3T	7T
PAT	7.5	10.0	10.5	12.9
MED	11.4	12.8	12.0	13.6
LAT	9.3	9.7	12.5	13.1
CON	8.1	10.4	9.3	9.7
Mean	9.1±1.8	10.7±1.4	11.1±1.5	12.3±1.8

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