Time-efficient interleaved ^{23}Na and ^{1}H acquisition at 7T

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PURPOSE: To design a time-efficient scanning protocol for a study of sodium concentration in knee cartilage in osteoarthritis (OA) patients. The study aims to scan both knees of healthy volunteers and patients within an hour. This abstract presents a method to obtain ^{1}H and ^{23}Na images simultaneously.

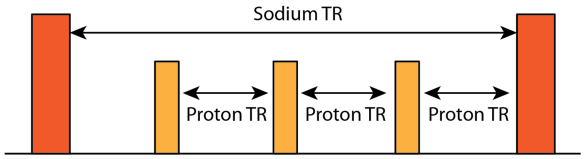

Fig.1. Interleaving three proton shots in one sodium

INTRODUCTION: Sodium MRI has gained popularity in recent years with the availability of whole body 7T MRI scanners for imaging the brain[1], kidney[2], and cartilage[3]. Higher field-strength yields increased signal-to-noise, which is beneficial for scanning the relatively low gamma ^{23}Na-nucleus. Nevertheless, sodium scans are typically time-consuming: 10 minutes and more are common scan times. In our OA scanning protocol the bulk consists of sodium scans, but a minimum ^{1}H scans are required for anatomical overlay and B_0-shimming. Preferably, we would like to include other contrast scans, e.g. ultrashort TE and T_2-mapping sequences. In our hospital scanning time for volunteers in the 7T facility is limited by the Ethics Review Board to 60 minutes. The goal is to use this time as effectively as possible for a ^{23}Na-MRI study on knee cartilage.

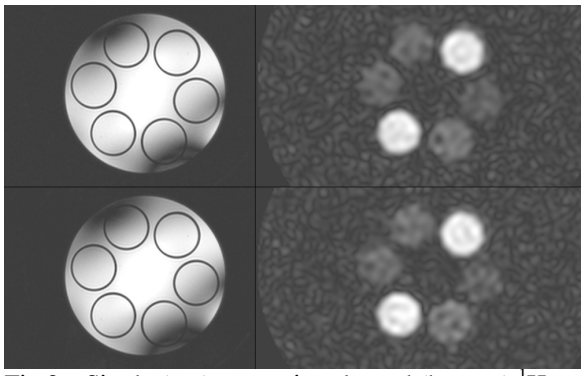
Fig 2a. Single (top) versus interleaved (bottom) ^{1}H (left). and ^{23}Na (right) scans of a phantom.

METHODS: The large separation in resonance frequency and the differences in relaxation behavior between ^{23}Na and ^{1}H allows to perform interleaved acquisitions. This has been shown for a rather rigid regime acquiring four ^{23}Na profiles during one ^{1}H interval[4]. In this abstract we introduce a new framework to interleave two or more different scan protocols (using different nuclei) at arbitrary time points during scan progression. The different sequence descriptions are stored on the data acquisition system in parallel tasks that can be switched on a microsecond basis. Thus, scan efficiency can be increased by interleaving several ^{1}H k-space lines into one ^{23}Na TR (Fig. 1). This high-level approach enables full flexibility in sequence design for ^{23}Na and ^{1}H independently.

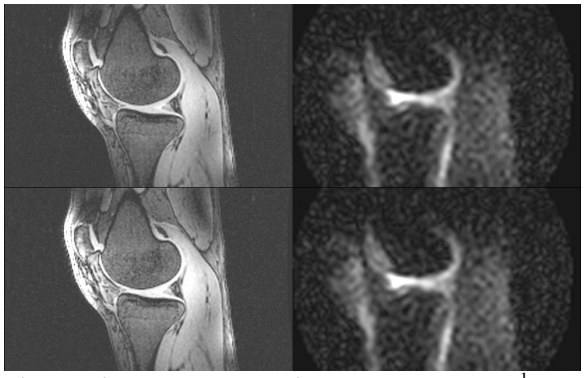
Fig 2b. Single (top) versus interleaved (bottom) ^{1}H (left) and ^{23}Na(right) scans in-vivo of a human knee.

The feasibility of the implementation has been tested on a whole body 7T scanner (Philips, Best) and an in-house built dual-tuned ^{23}Na and ^{1}H imbricated birdcage coil. The T_1 of ^{23}Na is approximately 25ms, resulting in a non-saturating TR of ~75-150 ms for a 90° tip angle. Depending on the exact sequence parameters this results in 75 – 125 ms "dead-time" that is available for ^{1}H acquisition. The protocol to study feasibility consisted of a ^{1}H 3D gradient echo (FOV 220x220x141mm³, 1mm isotropic resolution, TR 15ms, TE 2.5ms, tip angle 10°, acquisition time 7m46s) and a ^{23}Na spiral gradient echo (FOV 220x220x153mm³, 3x3x3mm³ resolution, TR 100ms, TE 1ms, tip angle 90°, 16 leafs, Tacq 10ms, acquisition time 10m24s). In the interleaved sequence five ^{1}H k-space lines are acquired in each ^{23}Na TR, resulting in a total scan duration for ^{1}H and ^{23}Na combined of 10m24s. Validation of the protocol has been performed in a cylindrical sodium phantom consisting of tubes with concentrations ranging between 50 and 250mM in 2% agarose. Three volunteers have been scanned.

RESULTS: Figure 2a shows the phantom images. ROIs were drawn for signal comparison of an interleaved and a separately acquired scan. No significant difference in SNR was found between the separate and interleaved ^{23}Na scans (paired t-test, 6 ROI pairs, p=0.72). The interleaved ^{1}H scan showed slight ghosting when using 3 shots, but none using 5 shots. Figure 2b shows results obtained in volunteers, there is no discernible difference between the separate and interleaved acquisitions.

DISCUSSION: Combining ^{23}Na and ^{1}H in an interleaved way is an effective method to reduce scanning time. The ^{1}H scans are acquired in the 'dead time' of the ^{23}Na sequence and are obtained for free. Therefore, these can be acquired at higher resolutions than if extra time were needed for such a scan. In addition to morphology the interleaved approach could potentially be used for real-time B_0 correction and/or real-time motion correction (where the motion correction information is of higher spatial resolution than the image to be corrected).

CONCLUSION: The high time efficiency of interleaving ^{23}Na with ^{1}H results in practical scanning times, which is essential for patient studies. The virtually simultaneous acquisition results in perfect image registration between the two scans and allows for more advanced applications in future, such as dynamic B_0 correction and motion correction.

1.Fleysher *et al. NMR Biomed* (2012). 2.Haneder *et al. Radiology* 260 (2011). 3.Madelin *et al. J Magn Reson* 207 (2010). 4. Lee *et al. MRI* 4**,** (1986).