Off-resonance correction of ^{23}Na spiral trajectories based on a ^{1}H B_0-map at 7T

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PURPOSE: In order to quantify sodium content, short echo time acquisitions are required to capture both the slow and the fast T_2^*-components in human tissue, for example articular cartilage[1]. A spiral trajectory through k-space yields shorter echo times and thus a higher SNR than comparable Cartesian acquisitions in equal scanning time, but these non-cartesian trajectories are more susceptible to the influence of B_0-inhomogeneities[2]. In spiral imaging B_0-inhomogeneities can cause severe blurring. A trade-off in spiral scanning can be made by selecting an appropriate value for the spiral acquisition time (Tacq): longer values give more signal but are also more influenced by off-resonance and vice versa. Using a dual-tuned ^{1}H-^{23}Na coil a proton B_0-map can be acquired for shimming, but here we also show it can be used for further improvement via off-resonance correction of the ^{23}Na data.

METHODS & MATERIALS: For the phantom experiment we acquired a set of images (scan parameters in Fig.1) with image-based B_0-shimming (2nd order) with varying Tacq using a cylindrical phantom consisting of tubes with sodium concentrations ranging between 40 and 250mM in 2% agarose. Using a frequency-segmented reconstruction method[3] and a proton B_0-map that was scaled to the resonance frequency of sodium the off-resonance effects were corrected in the phantom and in in-vivo knee acquisitions. The results are evaluated by calculating the signal-to-noise ratios (SNR) for different ROIs in the images. The scans were acquired using a whole body 7T scanner (Achieva, Philips, Best) and an in-house dual-tuned ^{23}Na and ^{1}H imbricated birdcage coil. The outer birdcage is a high-pass ^{1}H resonator; the inner birdcage is a low-pass ^{23}Na resonator. For the in-vivo experiments 3 healthy volunteers were scanned in compliance with ERB guidelines.

RESULTS: Figure 1 shows the results of off-resonance correction on the phantom acquisitions. The effect of off-resonance correction is clearly visible, especially in the long Tacq images. For Tacq=9ms there is little improvement in SNR since the short acquisition time minimizes the blurring artefact. As Tacq increases the sharpness of the images decreases and the improvement from off-resonance correction increases. Figure 2 shows the in-vivo knee images. Two ROIs were evaluated, one in the agarose reference phantom and one in the femoral cartilage. Using Tacq=20ms yields the best SNR in both ROIs. The off-resonance correction results in a modest increase in SNR.

DISCUSSION: The bulk of the effect of off-resonance in spiral imaging is reduced by image-based B_0-shimming. Adding the off-resonance correction results in a further increase in SNR, both in the phantom and in-vivo. To apply this method a post-shimming B_0-map is required. The extra scan time is negligible and the correction requires a few minutes calculation time. We expect that a further improvement can be achieved by implementing an exact conjugate phase reconstruction method in the scanner reconstructor software. Using this approach a modest gain in SNR can be achieved essentially for free, which is of benefit to quantitative sodium imaging.
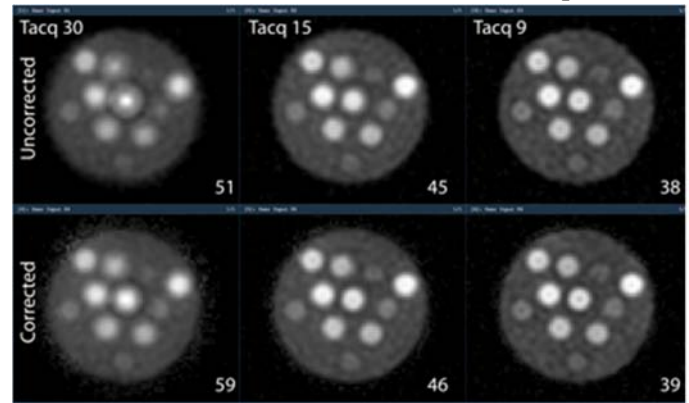

Figure 1. Transverse spiral sodium images of the phantom. *Top row*: uncorrected images, *bottom row*: off-resonance corrected images. *Left to right*: spiral Tacq equal to 30ms, 15ms, and 9ms. All scans acquired with same geometry (FOV 220x220mm², 112x112 matrix, 51 slices, 3mm thickness, stack of spirals, multi-shot, 16 interleaves, FA 90, TR 100ms, TE 2ms, NSA 8, duration 5m20s) and shim settings. The SNR of the central tube using the same size ROI for each image is shown in the bottom right corner of each image.
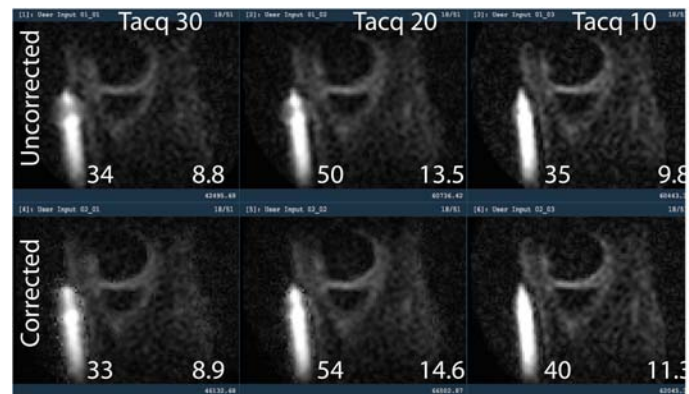

Figure 2. Sagittal in-vivo spiral sodium images of a healthy volunteer. *Top row*: uncorrected images, *bottom row*: off-resonance corrected images. *Left to right*: spiral Tacq of 30, 20, and 10 ms. All scans acquires with same settings as Fig. 1, except TE=1m, NSA=15, and duration 10m24s. Bottom left number in each image is the SNR of ROI in agarose reference phantom, bottom right number is the SNR of a ROI in the femoral cartilage.

1. Madelin et al, *NMR Biomed* **25** (2011). 2. Börnert et al. *MAGMA* **9,** (1999). 3. Man et al., *MRM* **37** (1997).