3D Phase Sensitive B1 Mapping

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INTRODUCTION: Sodium MRI shows promise in assessing cartilage health [1], characterizing tumors [2], detecting abnormal sodium levels in the kidneys [3], and assessing tissue damage following stroke [4]. However, relatively low ^{23}Na concentrations in biological tissues, a rapid bi-exponential signal decay, and a low gyromagnetic ratio make sodium MRI challenging. Recent improvements in MRI hardware, high field scanners, and the development of more efficient pulse sequences have enabled higher quality sodium MRI *in vivo* in reasonable scan times [5].

Accurate quantification of tissue sodium concentration is important for many applications. Quantitative analysis of sodium concentration requires accurate measurement of sodium T1, T2, and accurate B1 mapping. However, high noise levels in sodium MRI make accurate B1 mapping in reasonable scan times challenging. The problem is compounded when surface coils or other sodium-tuned transmit-receive coil configurations with significant B1 inhomogeneity are used to maximize SNR, as many B1 mapping methods are accurate over a limited range of flip angles.

A new phase-sensitive B1 mapping technique has been shown to work better than the standard dual-angle method in high noise situations and for a broader range of flip angles, although the technique is sensitive to off resonance [6]. Given sodium's lower gyromagnetic ratio (approximately ¼ that of ^{1}H) and the corresponding reduction in Larmor frequency, sodium MRI is significantly less susceptible to off resonance effects than proton MRI. Thus, the phase sensitive B1 mapping method seems a good candidate for the high noise and large B1 variations typical in sodium MRI.

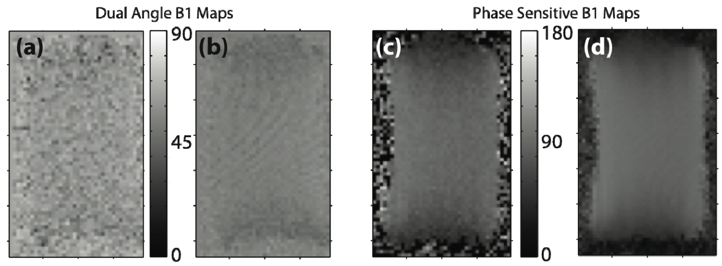

Figure 1: Dual angle sodium B1 maps for a single acquisition (a) and 20 averaged acquisitions (b). Phase sensitive sodium B1 maps for a single acquisition (c) and 20 averaged acquisitions (d). The phase-sensitive method yields much more robust B1 maps than the dual angle method. EPI phase artifacts are evident in both images.

In this work, we apply phase sensitive B1 mapping to sodium MRI and compare its performance to the dual angle method. B1 maps of a sodium phantom were acquired repeatedly with both the phase sensitive and dual angle methods to ascertain the performance and consistency of measurement of each method. We demonstrate that the phase sensitive sodium B1 mapping method yields similar information to the dual angle method, but performs more consistently in the high-noise environment characteristic of sodium MRI.

THEORY AND METHODS: The phase sensitive B1 mapping method (as described in [6]) makes use of a series of RF pulses that encode flip angle in signal phase, rather than in signal magnitude as with dual angle B1 mapping. Theoretically, the phase sensitive method provides more robust and repeatable measurement of B1 in high-noise situations across a larger range of flip angles, as described in [7]. Both the phase sensitive and dual angle B1 mapping methods were implemented using a 3D EPI sequence adapted for sodium imaging on a Siemens 3T MRI scanner. A uniform cylindrical sodium phantom ([Na+] = 250 mM) and sodium-tuned quadrature birdcage coil (insider diameter 16 cm) were constructed for the experiments.

Twenty B1 maps of the sodium phantom were acquired using the new phase sensitive method, along with 20 corresponding B1 maps using the dual angle method. Phase sensitive B1 mapping parameters were: TR/TE = 100/15 ms, EPI factor = 3 , FOV = 11.2x19x10 cm, matrix size = 38x64x20, readout bandwidth = 165 Hz/pixel, total scan time = 5 m 20 s. Dual angle B1 mapping parameters were: TR/TE = 100/15 ms, EPI factor = 3, FOV = 11.2x19x10 cm, matrix size = 38x64x20, readout bandwidth = 165 Hz/pixel, total scan time = 5 m 20 s. Each method has identical total signal readout time and identical total scan time.

The mean B1 values were computed on a voxel-by-voxel basis across the 20 maps for both the phase sensitive method and the dual angle method to validate that the two methods yield consistent B1 variations. Note that the phase-sensitive maps are centered around a nominal flip angle of 90 degrees (given a sensitive range of 0 to 180 degrees for the phase-sensitive method), while those of the dual angle method are centered around a nominal flip angle of 45 degrees (given a sensitive range of 0 to 90 degrees for the dual-angle method). Maps measuring the standard deviation of the 20 observations at each voxel were then computed for both methods to determine which method provided more consistent measurement of B1 values in this high-noise environment.

RESULTS AND DISCUSSION: Sample sodium B1 maps for each method are shown in Figure 1, along with the resulting means across the 20 measurements. The mean images reveal consistent variations in B1 (despite the different nominal flip angle), suggesting that both methods yield consistent B1 data. Standard deviation maps are shown in Figure 2. As can be seen, the phase-sensitive method has a consistently lower standard deviation of measurement (despite the higher nominal flip angle), indicating much more consistent performance than the dual angle method. As such, the new phase sensitive method seems a good choice for rapid 3D B1 mapping in sodium MRI. While promising, further work is needed to validate whether similar gains can be obtained *in vivo*.

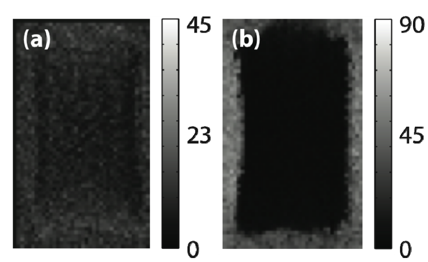

Figure 2: Standard deviation of the sodium B1 maps for (a) the dual angle method, and (b) the phase sensitive method as measured across the twenty acquisitions.

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