In Vivo Sodium Imaging and Relaxometry of the Breast at 3T

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INTRODUCTION: Breast cancer is the most common type of cancer affecting women, and early detection is crucial for effective treatment and increased survival. Mammography is the most widely used imaging modality for breast cancer screening, but has inadequate sensitivity[1]. Contrast-enhanced proton MR imaging has higher sensitivity for detecting breast tumors, but limited specificity[2]. Sodium MRI shows potential since it does not require the use of an exogenous contrast agent, making it attractive as a complement to proton imaging. Neoplasms are known to disrupt some of the sodium regulation mechanisms, so the intra- and extra-cellular concentrations may change in tumors.

In this work, we measured *in vivo* sodium T_1 and T_2* of glandular breast tissue with B_1-correction at 3T. Accurate characterization of sodium T_1 and T_2* in the tissue of interest is required for sequence parameter optimization and, in some cases, may be a marker of underlying physiology. We show preliminary results showing an increase in the sodium T_2* within tumors.

METHODS: A fast gradient-spoiled sequence using the 3D cones k-space trajectory[3] and a rapid (0.64 ms) RF excitation was developed for sodium imaging on a 3T GE whole-body scanner. This centric trajectory permits short echo times with very high SNR efficiency, while providing a relatively smooth k-space weighting and making efficient use of gradient resources.

The right breast of 3 healthy women (ages 26 to 37), and 4 subjects with tumors (ages 24 to 51) was scanned using a dual-tuned breast coil. This coil consists of two concentric Helmholtz pairs, the outer one tuned to protons and the inner one tuned to sodium[4]. The protocol used on the healthy volunteers consisted of the flip angle measurements, T_1 measurements, T_2* measurements, and a high-resolution image using the sodium coil. A proton image was also acquired as an anatomical reference. For the cancer subjects the only sodium acquisition was the high-resolution image obtained pre-contrast. We also acquired a T_2* map for a single subject with breast tumors (age 25).

To obtain a flip angle map, we used the double-angle method[5], which requires the acquisition of two images, with flip angles α and 2α, and TR long enough to allow for full T_1 recovery. The imaging parameters were: TE/TR = 0.6/300 msec, 6x6x6 mm resolution, FOV of 14x14x49 cm, and prescribed flip angles of 45° and 90°. We averaged two acquisitions in under 4 min. For the T_1 map calculations, we acquired three images with different flip angles. The imaging parameters were the same as described above, except TR = 35 msec and prescribed flip angles of 35°, 50°, and 70°. We averaged five acquisitions in less than 5 min. We calculated a T_1 value for each voxel using the Driven Equilibrium Single Pulse Observation of T_1 (DESPOT1)[6] algorithm with the flip angles correction using the measured flip angle map. To generate the T_2* map, we acquired images with different echo times (TE = 1, 2, 4, 6, 8, 12, 16, and 24 msec) and found T_2* as the least-squares solution to the T_2* decay equation. The other imaging parameters were the same as above, with TR = 50 msec and prescribed flip angle of 70°, for a scan time of less than 2 min. per image. The high-resolution sodium image was obtained with TE/TR = 0.6/35 msec, 2x2x4 mm resolution, FOV of 20x20x32 cm, prescribed flip angle of 70°, and 10 signal averages for a total scan time of 13 min. Finally, the proton image was acquired with an SPGR sequence with multiple echoes to generate fat and water images using least-squares multi-point separation technique (IDEAL)[7].

RESULTS: For the patients with breast tumors the regions identified with lesions on the post-contrast proton images also appear brighter on the pre-contrast sodium images, with the sodium signal over the lesions being 3 to 5 times brighter than the signal over the healthy glandular tissue. The T_2* maps on the regions corresponding to the tumors show typical values of 27 and higher, and always higher than the healthy tissue. For the healthy volunteers the T_2* maps show typical values between 12 and 25 msec, while the typical T_1 values are between 35 and 50 msec. These measurements agree with previously published values[8]. Even though the measured flip angle is near the prescribed one, the variation within the coil volume is significant enough to warrant the corrections used here: the T_1 values calculated without these corrections differ by tens of msec. This flip angle map can also be used as an estimate for the receive profile of our transmit-receive coil for the purpose of ^{23}Na quantification.

DISCUSSION: This technique demonstrates measurement of both *in vivo* sodium T_2* and T_1 in human breast tissue with good resolution in feasible clinical times. Further development is needed to improve SNR of the measurements and minimize the total scan time. Our preliminary results also show that both the sodium signal intensity and the sodium T_2* could be higher in regions with lesions than on healthy glandular tissue.

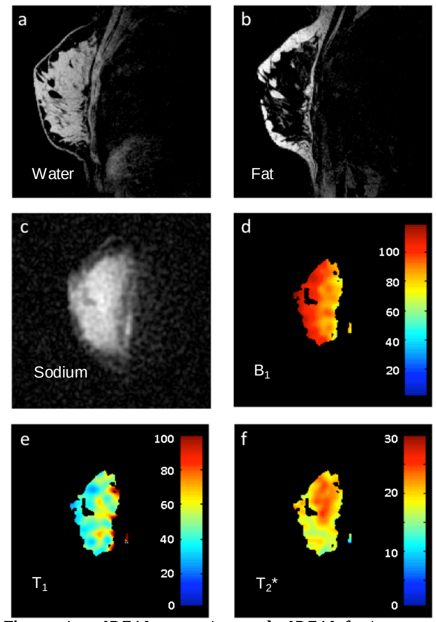

Figure 1. **a**: IDEAL water image. **b**: IDEAL fat image. **c**: High-resolution sodium image. We can see the correspondence between this image and the IDEAL water image, since sodium is more soluble in water than in fat. **d**: Flip angle map for a prescribed flip angle of 90°. **e**: T1 map. **f**: T2* map. The low-resolution maps where only calculated where the signal of the high-resolution sodium image was at least half of the

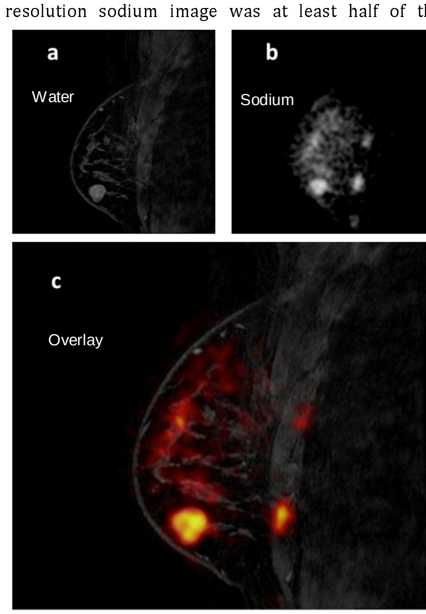

Figure 2. **a**: Post-contrast IDEAL water image showing tumor. **b**: Pre-contrast high-resolution sodium image. The leftmost bright spot correspond to the tumor, while the other bright spots on the right are the intercostal cartilage. **c**: Overlay of sodium image on the post-contrast water showing the correspondence between the images.

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REFERENCES:

[1] C. K. Kuhl, *et al., Radiology*, **215(1)**:276-279, 2000.
[2] D. Saslow, *et al., CA Cancer J Clin*, **57(2)**:75-89, 2007.
[3] P. T. Gurney, *et al., Mag Res Med*, **55**:575-582, 2006.
[4] A. Nnewihe, *et al., Proc of 16th ISMRM*, p. 1114, 2008.
[5] E. K. Insko, *et al., Magn Reson* **103**:82-85, 1993.
[6] K. A. Christensen, *et al., J Phys Chem*, **78**:1971-1977, 1974.
[7] S. B. Reeder, *et al., Magn Reson Med*, **51(1)**:35-45, 2004.
[8] R. Reddy *et al., Magn Reson Med*, **36**:697-701, 1998.