Optimized Sodium Imaging of the Human Brain at 4.7 Tesla

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Introduction: Sodium imaging in-vivo is limited by low concentrations (when compared with proton) and very rapid T_2 relaxation. However, sodium imaging benefits from rapid T_1 relaxation facilitating the use of 3D imaging techniques. In order to obtain the highest quality images possible (pertaining to SNR and image resolution) it is essential to minimize TE. This is best accomplished with the use of 3D, center-out, projection acquisition. But, projection acquisition suffers from a high degree of non-uniform sampling density (i.e. the center of k-space is sampled much more often that the outer edges of k-space) which increases the noise variance within the image. An excellent solution to this problem is twisted projection acquisition (1) and its implementation in 3D (2). Unfortunately, twisted projection acquisition is rarely used due to its complexity, and the difficulties associated with regridding. This abstract presents an implementation of twisted projection acquisition at 4.7 Tesla (the largest magnetic field strength at which this has been implemented) along with the application of recent regridding techniques. The images presented benefit from an excitation pulse-length / flip-angle optimized steady-state response. Although this introduces relaxation weighting into the images, higher quality images (SNR for a given resolution) can be obtained for sodium in the human brain.

Methods: Optimization for sodium imaging at 4.7 Tesla was performed using spin-sequence-simulation with a T_{2fast} of 1.7 ms and a T_{1ave} of 36 ms (bulk parameters measured with sodium relaxometry). Flip-angle and excitation pulse-length were varied, and for each combination an associated TR was calculated to maintain a constant specific absorption rate (SAR). The delay between the excitation pulse and the start of acquisition (or the center of k-space in centric imaging) was maintained at 0.18 ms (which includes delay for ring-down and Nyquist filter transient response). Relative SNR was determined for a constant length experiment. The images presented were acquired using a 4.7 Tesla Varian Inova whole-body imaging scanner and an in-house designed 53 MHz sodium head coil. The sequence presented was tested on three healthy volunteers. K-space was sampled using 3D twisted projection acquisition with 5000 projections (twist of 0.5) at an acquisition voxel size of 3.2 mm isotropic. The following parameters were chosen based on optimization: excitation pulse-length – 0.9 ms (yielding a TE of 0.63 ms); flip-angle – 65°; and repetition – 30 ms. Using this pulse-length, flip-angle and TR, SAR was maintained below 2 W/kg. The readout length was 18.7 ms, four averages were acquired, and the imaging time required to perform the scan was 10 minutes. Images were regridded using a Kaiser-Bessel convolution kernel on a 1.2 times over-sampled grid (3) and sampling density was compensated using an iterative approach (4). Images were Hamming filtered following regridding to remove any residual ringing.

Results and Discussion: Results from the pulse-length / flip-angle optimization are given in **Figure 1**. It is readily apparent from this figure that a short 90° RF pulse in association with a longer TR (i.e. minimally T_1 weighted case) produces significantly less SNR than an implementation with a shorter TR for a constant scan time. It can also be seen that a longer RF pulse with a greater flip-angle can generate approximately 10% more SNR than an optimal flip-angle implementation of the shortest pulse-length (and shortest TE). Representative sodium human brain images are shown in **Figure 2**. Reduced over-sampling during reconstruction makes possible zero-filled interpolation to 1.2 mm isotropically with a 256 x 256 x 256 data set. The average SNR within brain tissue is approximately 17.

Discussion: To obtain truly quantitative sodium images, the imaging sequence must be free from relaxation weighting. However, considering that intracellular sodium ions may exhibit extreme T_2 relaxation (i.e. T_{2fast} < 1 ms), this weighting seems unavoidable (except perhaps in the case where very small flip-angles are used in conjunction with very short pulses and single point imaging). An alternative may be to produce the highest quality images possible and to correct for weighting with a-priori knowledge of in-vivo relaxation – or to search for correlation between relaxation weighted images and pathology. Previous images acquired with twisted projection acquisition at 1.5 Tesla **(5)** and 3 Tesla **(2)** have used 0.4 ms excitation pulses, 90° flip-angles, and longer TR values. Using pulse-length / flip-angle optimization good quality, high-resolution sodium images of the human brain have been acquired with an acquisition voxel size of 0.033 cm^3 in 10 minutes.

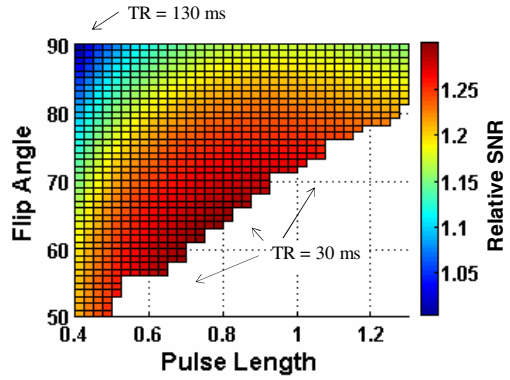

Figure 1 (Above) Sodium imaging optimization from simulation at 4.7 Tesla for constant scan duration and SAR (~2 W/kg in this case). Each excitation pulse-length and flip-angle combination is associated with specific TR to yield constant SAR. SNR is given relative to a flip of 90°, a pulse-length of 0.4 ms and a 130 ms TR (top left corner). The minimum TR allowed was 30 ms (for readouts and gradient crushers) – the value along the jagged cutoff. Note, optimum SNR is not associated with shortest possible pulse-length (and shortest possible TE).

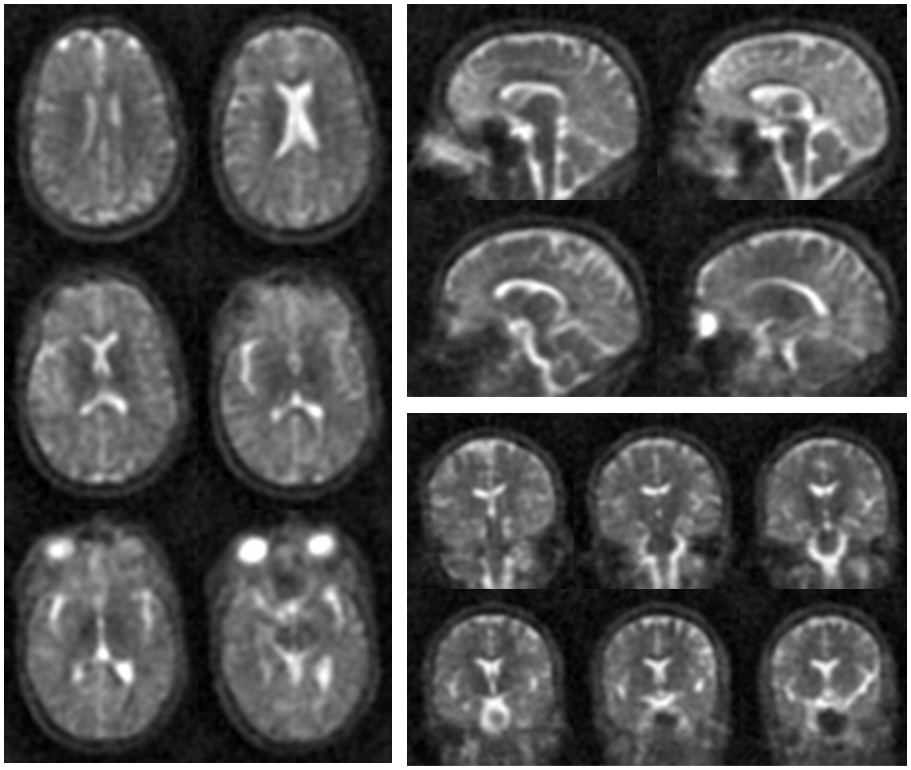

Figure 2 (Right) Representative sodium images from a healthy volunteer at 4.7 Tesla using twisted projection acquisition and pulse-length flip-angle optimization.

Flip-Angle: 65° **Pulse-Length:** 0.9 ms **TR:** 30 ms
Scan Length: 10 minutes
SAR: < 2 W/kg
Acquisition Voxel Size: 3.2 mm isotropic

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