# MR Imaging of Sodium using a 3D Cones Acquisition

J. A. Stainsby[1], P. T. Gurney[2], B. S. Li[3], F. C. Damen[4], and K. R. Thulborn[4]

[1]Global Applied Science Laboratory, GE Healthcare, Toronto, Ontario, Canada, [2]Stanford University, California, United States, [3]Global Applied Science Laboratory, GE Healthcare, Chicago, Illinois, United States, [4]Center for MR Research, University of Illinois at Chicago, Chicago, Illinois, United States

**Introduction**: Quantitative tissue sodium concentration (TSC) has been shown to be an effective and direct measure of tissue viability based on sodium ion homeostasis [1]. An accurate assessment of viability is essential for interpreting measured TSC values for clinical decision-making in stroke or tumor therapy. Due to the short T2 relaxation times and low in vivo concentrations, quantitative sodium imaging requires acquisitions with short echo times and efficient SNR behavior. Twisted Projection Imaging (TPI) has been demonstrated as an effective, efficient acquisition strategy that provides extremely short echo times and increased sampling efficiencies compared to Cartesian or Radial acquisitions. TPI acquisitions have some limitations due to interdependence of design parameters. Recently a 3D Cones sampling scheme has been proposed that overcomes some of these limitations [2]. The purpose of this study was to compare sodium imaging using an existing TPI acquisition strategy to a sodium imaging acquisition using a 3D Cones trajectory.

**Theory:** While TPI trajectories aim for a uniform sampling density throughout k-space, the 3D Cones trajectory attempts to minimize the acquisition time to cover a given FOV. TPI trajectories have the advantage of a closed form analytic solution but at the cost of a dependence of system parameters (gradient amplitude/slew rate) on scan prescription parameters (FOV, resolution, p-value). For example as described by Boada et al. [3], the maximum gradient slew rate of a TPI waveform depends on the maximum waveform amplitude, the prescribed FOV and radius to start twisting (p-value). In addition the readout duration depends on gradient amplitude, prescribed resolution and p-value. This interdependence of parameters results in typically low readout gradient amplitudes that are fixed based on prescription values. The 3D Cones trajectory design is a numerical optimization algorithm that tends to separate the dependence on system and prescription parameters. Conceptually, this can be considered as designing the desired k-space trajectory to satisfy scan prescription parameters, and utilizing the maximum available gradient hardware parameters to traverse this trajectory. A 3D Cones acquisition should therefore have more flexibility for optimizing scan parameters in the context of sodium imaging.

**Methods**: A 3D cones imaging sequence was developed for imaging sodium on a 3T GE Signa EXCITE HD scanner (Waukesha, WI, USA). In vivo brain images were acquired using existing TPI methods as described in [3] (TR=120ms, radial fraction=0.3, 0.16G/m gradient strength, resolution 4.4x4.4x4.4mm$^3$, FOV=26cm, 44ms readout window, 4 averages, with a scan time of 8.8min) They were compared to images acquired with the 3D cones sequence using comparable sequence parameters (TR=120ms, 4.0G/cm gradient strength, resolution of 4x4x4mm$^3$, FOV=26cm, 22ms readout window, 36 averages), with a scan time of approx. 17min. Note that implementation limitations prevented using a 44ms acquisition window with the cones sequence and to preserve the total data acquisition time the cones scan time was twice that of TPI. The minimum TE times from both acquisitions were approximately equivalent at 360us. Reconstruction and quantification were performed offline. SNR comparisons were conducted.

**Results**: Fig 1 shows images from the two acquisitions and Table 1 compares SNR in the ROIs illustrated in Fig 1.

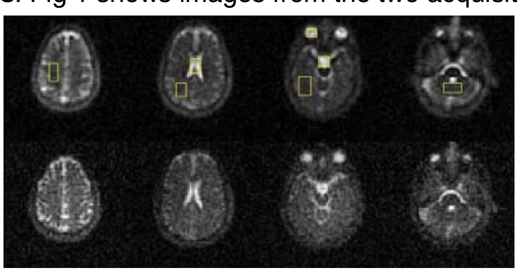

**Figure 1**: Sample Na images using TPI (top) and 3D Cones (bottom).

| ROI | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| TPI | 12.3 | 13.3 | 42.7 | 36.3 | 40.5 | 12.4 | 11.1 |
| Cones | 9.6 | 9.8 | 20.5 | 17.6 | 25.0 | 9.4 | 8.9 |
| Ratio | 1.3 | 1.4 | 2.1 | 2.1 | 1.6 | 1.3 | 1.2 |

**Table 1**: Comparison of SNR values in ROI's illustrated in Fig. 1. SNR differences are generally accounted for by the difference in resolution between TPI and 3D Cones.

**Discussion**: The TPI and 3D Cones acquisitions gave comparable results once the difference in voxel volume is accounted for (TPI voxels were 1.33 times larger than 3D Cones). The increased efficiency in the 3D Cones trajectories allowed for the same 3D volume to be sampled with only 241 TRs compared to 946 TRs for TPI. Due to the low SNR in TSC measurements, increased averaging with cones is needed to achieve accurate quantitative measurements. As a result of this work, we have realized the need for changes to the 3D Cones trajectory design algorithm to allow the trade-off of readout efficiency for SNR efficiency. This will provide an optimized scheme for the low-SNR regime. The increased flexibility in the 3D Cones acquisition should then make it easier to independently optimize sodium imaging protocols for prescription parameters such as resolution, FOV, readout duration, and number of averages. Furthermore in other applications that are not as SNR limited, 3D Cones may have additional advantages over TPI.

**References**: 1. KR Thulborn, et al., Radiology, 1999; 2. PT Gurney, et al., MRM, 2006; 3. FE Boada, et al., MRM, 1997.