Improved Twisted Projection Imaging with Low Gradient Slew-Rates

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INTRODUCTION: For 3D projection imaging schemes, the gradient waveform design usually incorporates at least two parts. The first part must be optimized to address the high sampling density near the origin of k-space and the second part must be optimized to reduce the number of projections required, whilst achieving optimum sampling in the outer regions of the k-space sphere. Twisted Projection Imaging (TPI) is an example of such a method which is ideally suited for quantitative imaging of nuclear spins with fast T_2 decay (1). It has been successfully applied to ^{23}Na MRI of patients with cancer (2) and heart disease. However, the design algorithm for the k-space trajectory is such that high slew rate demands often limit the choice of readout-time or resolution, even when the maximum gradient amplitude for ^{23}Na MRI applications is low in order to minimize bandwidth to maximize the signal-to-noise ratio. Accordingly, we adapted the algorithms and pulse program to obtain a far more slew-rate-friendly gradient design. Voronoi analysis was used to calculate the sampling Density Correction Factors (DCF) that are needed for the image reconstruction. The new k-space sampling scheme was tested on a phantom and compared with the original TPI sequence.

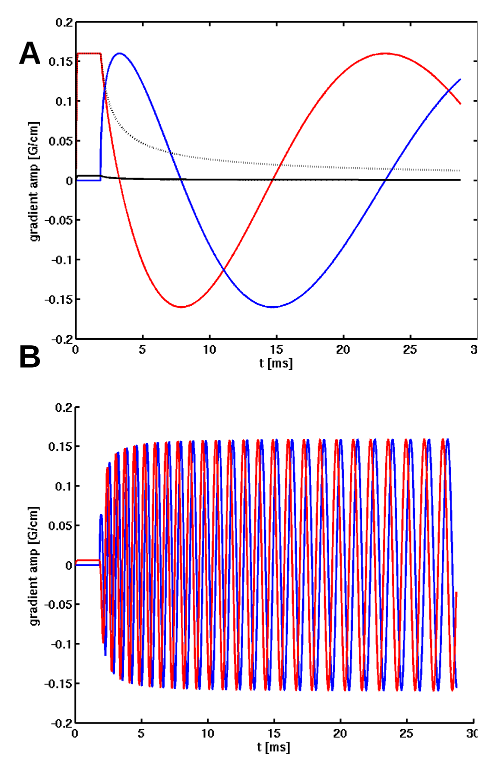

Figure1 ^{23}Na TPI gradient waveforms Gx (red) and Gy (blue) and Gx (solid black) for the first ring (A) and Gx and Gy for the last ring. The new method uses only the base waveforms shown in (A)

The TPI gradient waveforms are designed to yield uniform sampling in the spiral part of the trajectory. The k-space trajectory radius in the spiral part is always:

$$\left\|\bar{k}(t)\right\| = \sqrt[3]{3\gamma G_{\max} k_0^2 t + k_0^3} \qquad [1], \text{ let } \chi(t) = \sqrt{\frac{\left\|\bar{k}(t)\right\|^4}{k_0^4} - 1} \qquad [2]$$

The azimuthal angle φ is: $\varphi_r(t) = \frac{1}{2a_r}\left(\chi(t) + \arctan\frac{1}{\chi(t)}\right) + \varphi_{i0}$ [3]

The original TPI algorithm has the factor $2a_r$ in Eq 2 as 2sinθ a function of polar angle θ or the ring number, r. This creates different φ functions for each ring and thus requires a different gradient waveform for each ring except for the Z-gradient where only the maximum amplitude is varied. The X and Y waveforms for low θ's have high slew-rates, as can be appreciated from the gradients shown in Figure 1B. However, with a_r=1 for all rings only three basic gradient waveforms are required, and all azimuthal and polar angles can be covered by varying the maximum gradient amplitudes for the X, Y and Z gradient waveforms.

METHODS: Gradient waveforms were designed for ^{23}Na projection imaging at 1.5T with a readout time of 28 ms with a projection reduction factor of 0.5 (= spiral fraction) 1240 projections were for 44 cones and a target resolution of 6mm isotropic with 0.16 G/cm maximum gradient strength. ^{23}Na images were collected on a GE 1. 5 T Signa scanner (Rev 5.8) with TR =100 ms and 4 averages in under 9 min. In the new scheme the projection azimuthal and polar angles were covered by varying the maximum gradient amplitudes of the three base waveforms. Images were reconstructed with trilinear gridding. DCF were calculated in 12 min. with the *Qhull* algorithm (3) in Matlab v7 (Mathworks, Natick, MA) on an Apple (Apple, Cupertino, CA).

RESULT AND DISCUSSION: The relative sampling volumes calculated showed that the sampling density distribution of the new trajectories was very similar to that of the original TPI trajectories and phantom tests yielded practically indistinguishable images (Fig. 2). The very high slew rates of the last ring trajectories of the original sequence were avoided altogether.

Thus, modification of the TPI waveform design can eliminate the high slew rates for k-space cone trajectories with a small polar angle without degrading image quality.

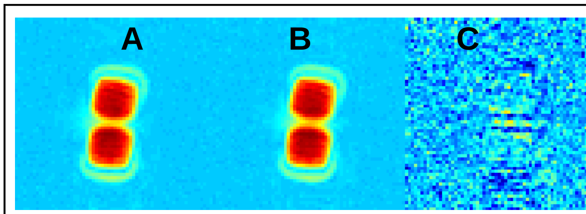

Figure 2: ^{23}Na MRI of two bottles containing 150 mM NaCl in water. Slices of 3D images obtained with (A) the original TPI k-space trajectories, (B) the reduced slew trajectories. (C) 10 times the difference between A & B.

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