q-Space Trajectories for Faster q-Space Sampling

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Introduction:
White matter tractography is gaining popularity in many applications, such as pre-surgical planning and mapping cortical connections [1]. However, many regions of white matter exhibit complex fiber crossing behavior, necessitating lengthy sampling schemes such as DSI [2] or q-ball imaging [3] to properly resolve these crossings. These techniques sample q-space to estimate the orientation distribution function (ODF) of white matter fibers. The resultant long scan times may prevent these techniques from achieving widespread clinical utility. A typical diffusion-weighted pulse sequences using one of these q-space sampling schemes acquires one point in q-space in each TR. In techniques with points at multiple radii in q-space, this results in multiple diffusion preparation (DP) steps in the same or similar directions, resulting in redundant travel through q-space. We propose that following image acquisition, additional diffusion weighting can be applied to travel to another q-space point and collect an image. In this way, inner q-space points are used more efficiently as an incremental step to outer points, as shown in Figure 1. We refer to this concept as a q-space trajectory, to reflect the similarity with sampling k-space.

Methods:
All experiments were performed on a Siemens 3.0T system (Trio, Siemens Healthcare) in accordance with local IRB protocol. A standard twice-refocused spin echo EPI pulse sequence was modified to allow for multiple DPs and EPI readouts following excitation. Each TR becomes longer as a result, but the overall reduction in number of TRs by a factor of q-space trajectory length and shorter DP time results in overall acceleration. This is shown in Figure 1, where a single 2-point q-space trajectory TR is shorter than the equivalent 2 TRs from a conventional sequence.

An asymptomatic volunteer was imaged (FOV = 231mm, 96x96 matrix, 54x2.4mm slices, BW = 1390Hz/px, DSI half sphere gradient table with 128 directions, GRAPPA [4] R=2) with a conventional sequence (TE/TR = 88ms/6900ms, TA = 14:50) and the q-space trajectory sequence (TE1/TE2/TR = 81ms/190ms/11800ms, TA = 12:47). Informed consent was obtained in accordance with local IRB. ODFs were reconstructed from the diffusion-weighted images using the generalized q-sampling technique [5] and representative examples from the corpus callosum are shown in Figure 2.

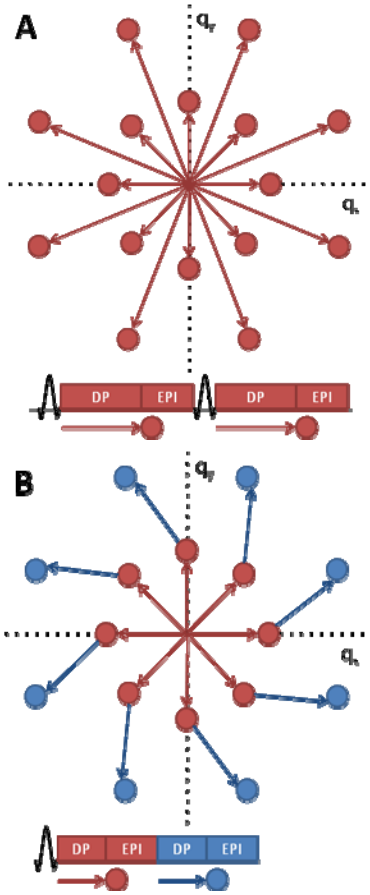

Figure 1.Central "slice" of a 2-shell q-space sampling scheme using a standard (A) and q-space trajectory (B) sequence. The pulse sequence is shown below each q-space plane and shows RF excitation, diffusion preparation (DP) and EPI readout (EPI).

Results and Discussion:
The ODFs shown in Figure 2 demonstrate that the q-space trajectory technique achieves comparable fiber resolution as the conventional technique. Because the q-space trajectory approach is independent of the reconstruction scheme, other techniques such as compressed sensing and multi-band imaging could be used in conjunction with our technique to further improved acquisition throughput. Such an approach should allow better than 50% reduction in data acquisition time for DSI and other lengthy tractography acquisitions.

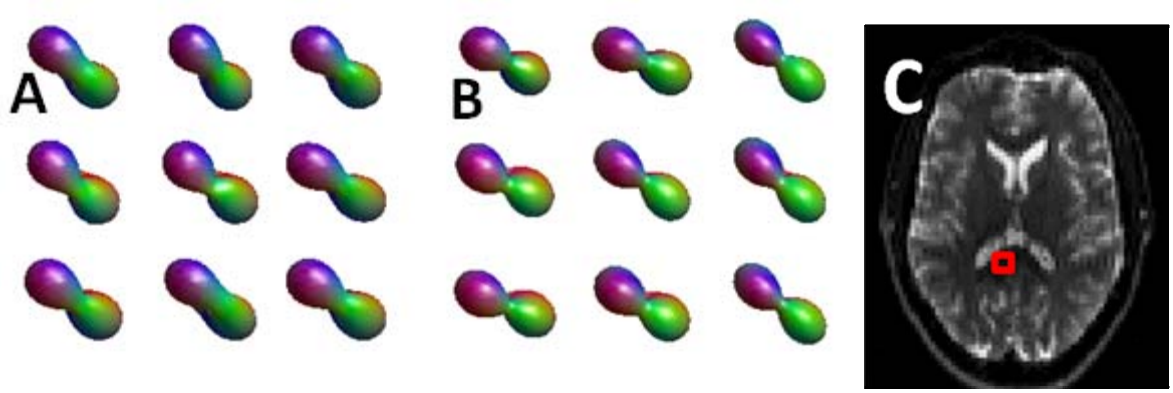

Figure 2. Representative ODFs reconstructed from the corpus callosum standard (a) and q-space trajectory (b) sequences. Superior/inferior direction is in blue, left right in red, and anterior/posterior in green. The red box in the b=0 image (c) shows the region of interest.

Conclusions:
We present the initial feasibility of using a q-space trajectory to collect images at multiple q-space points per TR.

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