Improving the Efficiency of Diffusion Spectrum MRI Through Radial Acquisitions in q-space

Fernando Emilio Boada[1] and Steven Yutzy[2]
[1]Radiology, New York University, New York, New York, United States, [2]Radiology, University of Pittsburgh, Pittsburgh, Pennsylvania, United States

INTRODUCTION

Many reports (1) have demonstrated the unique ability of diffusion spectrum imaging (DSI,2) to non-invasively depict the human brain's microstructural information with superb rendition of well-known anatomical details, including complex intra-voxel fiber crossings (3). DSI derives such capabilities from its model-independent determination of the orientation distribution function (ODF) through direct sampling of the ODF's 3D Fourier transform in q-space (2). As discussed elsewhere (4), adequate angular resolution is essential in order to accurately map fiber crossings in the brain. Current implementations of DSI, sample q-space on a Cartesian grid and, as a consequence, the resulting angular resolution is directly proportional to the inverse of the largest distance sampled in q-space. In this geometric arrangement, increased angular resolution requires larger q-space radii, which, in turns, leads to a cubic increase in the required number of samples and a sometimes prohibitive data acquisition time (>40mins). In this paper, we present a methodology for radially symmetric DSI acquisitions that allows improving the angular resolution in a more efficient fashion than conventional Cartesian DSI.

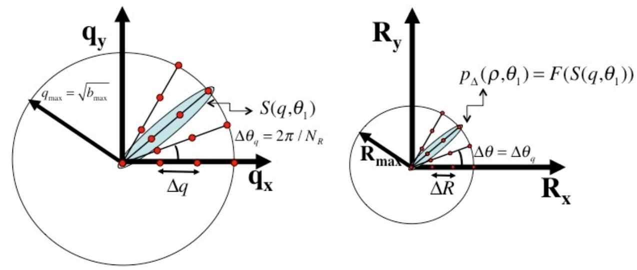

Figure 1: *CST and angular resolution in 2D. On a Radial grid, higher angular resolution can be achieved for the same b-value by angular oversampling on a circle of radius qmax.*

METHODS

The salient feature of a radial DSI raster is that every radial line acquired in q-space leads to an independent (i.e., non interpolated) value for the radial ODF at the same exact angular location (central section theorem, CST, figure 1) in the spatial domain (R-space). Thus, the number of angular ODF samples is equal to the number of intersections of the radial raster with the surface of a sphere. A theoretical demonstration of this finding is presented below. First, for a particular spatial position r, and direction (θ,φ), the ODF is defined as:

$$ODF(\vec{r},\theta,\varphi) = \int p_\Delta(\vec{r},\rho\hat{u})\rho^2\, d\rho$$

where, $\hat{u} = (\cos\varphi\sin\theta, \sin\varphi\sin\theta, \cos\theta)$ is the unit vector in the direction specified by (θ,φ) and $p_\Delta(\vec{r},\rho\hat{u})$ is the water displacement function. Because of the CST, the values of the water displacement function along $\hat{u}$ are identical to the values of the one-dimensional Fourier transform of the Radon transform of the q-space samples along the same line ($\hat{u}$), that is:

$p_\Delta(\vec{r},\rho\hat{u}) = \int_{\hat{u}} (R_{3D}S)(\vec{r},\rho\hat{u}) e^{-i2\pi\rho q} dq$, where $(R_{3D}S)(q\hat{u}) = \int_{\hat{u}} S(\vec{q}\,')\delta(\vec{q}\,'.\hat{u} - q)d\vec{q}\,'$ is the 3D Radon transform of $S(\vec{q})$, the measured q-space data. Combining these equations, it can be shown that:

$$ODF(\theta,\varphi) = \int S(\vec{q})F(\vec{q},\hat{u})d\vec{q},\ F(\vec{q},\hat{u}) = \frac{R_m^3}{4}\left(\frac{\sin(2R_m\pi\vec{q}.\hat{u})}{2R_m\pi\vec{q}.\hat{u}} + \frac{2\cos(2R_m\pi\vec{q}.\hat{u})}{(2R_m\pi\vec{q}.\hat{u})^2} - \frac{\sin(2R_m\pi\vec{q}.\hat{u})}{(2R_m\pi\vec{q}.\hat{u})^3}\right),$$

where R_m is the maximum displacement distance being probed. This last expression, being analytical, allows calculating the ODF through direct matrix multiplication of the measured data $S(\vec{q})$ with the geometry matrix $F(\vec{q},\hat{u})$.

RESULTS

Figure 2 presents a comparison between a conventional and radial DSI reconstruction for a normal human volunteer. The data were acquired with a double-refocused spin echo EPI sequence on a 3T scanner (TIM Trio, Siemens Medical Systems, Erlangen) using a 32-channel coil. Reconstruction of the radial DSI data was performed off-line using custom-built software.

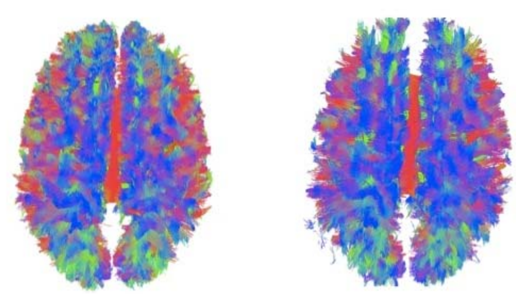

Figure 2: *Conventional (left) and radial (right) DSI reconstructions for the same normal human volunteer (b_{max}=7,000s/mm^2). The conventional DSI scan used 256 samples on a Cartesian grid while the radial DSI used 92 co-linear gradient directions. There is clearly an excellent correlation between these results, which is the result of the radial's raster improved angular coverage.*

CONCLUSIONS

Results demonstrate that radial sampling in q-space is ideally suited for exploiting the symmetry of the ODF. This observation allows improving the angular resolution without a concomitant increase in the maximum required b-value and with only a quadratic relationship with the number of required samples.

REFERENCES: [1] Weeden VJ, et al., Science, **335:**1628,2012. [2] Callaghan P., Principles of Nuclear Magnetic Resonance Microscopy, Oxf. Univ. Press, 1994. [3] Fernandez-Miranda JC, et al., Neurosurg., **71:**430, 2012. [4] Weeden VJ, et al., MRM, **54:** 1377, 2005. **Supported in part by PHS Grant R01-MH088370-01.**