Improved angular resolution at low b-values in Diffusion Spectrum Imaging through Radial acquisition in q-space

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Target audience: Scientists and clinicians interested in acquiring Diffusion Spectrum MRI at lower b-values.

Impacts: To demonstrate that radial q-space sampling for Diffusion Spectrum MRI improves ODF sampling and angular resolution at lower b-values as demonstrated by computer simulations and in a clinical scanner in vivo.

Diffusion Spectrum MRI (DSI) [1] has been shown to non-invasively image the anatomical details of the microstructure of the brain, including complex distributions of intravoxel fiber orientations [2,3]. These properties depend on the model-independent determination of the Orientation Distribution Function (ODF) through the sampling of the ODF’s Fourier transform in q-space [1]. When studying intravoxel fiber distributions, the angular resolution of the sampling method is crucial in accurately identifying fiber crossings [4]. In conventional DSI implementations, q-space is sampled on a rectangular grid and, consequently, the angular resolution is proportional to the inverse of the largest distance sampled in q-space. Hence, to increase the angular resolution, more shells have to be acquired, resulting in a cubic increase for the number of required samples and the acquisition time.

In the recently proposed Radial q-space sampling for q-space [5,6], the nominal angular resolution is primarily determined by the number of radial lines along which samples are acquired rather than by the number of shells. Hence, in theory, the angular resolution is independent of the number of shells (above a certain threshold). This results in improved DSI reconstructions at a lower number of shells, a lower number of q-space samples and at shorter acquisition times. An additional advantage of the radial q-space sampling is that it avoids interpolation errors introduced in rectangular sampling of q-space.

Methods: Experimental: For both Cartesian (rectangular) and Radial q-space sampling schemes, in vivo brain data of a healthy volunteer were acquired during the same session using a twice-refocused spin echo sequence. The radial sampling scheme [5,6] acquires several q-space samples (= number of shells) along a number of radial lines (e.g. 59). This has the advantage that every radial line acquired in q-space is directly connected to a value of the radial ODF at the same angular location in the spatial domain by the Fourier slice theorem [5]. The DSI acquisition was performed on a 3T scanner (Skyra, Siemens, Erlangen) using a 32-channel head coil (bmax=6000 (cartesian)/4000 (radial), TR = 1500, 2.3×2.3×5 mm resolution, 10 slices, multiband acceleration of 2 [7], TE = 133ms(Cartesian)/114ms(radial)). The conventional rectangular sampling was acquired in 709 samples (6 shells, half sphere, 17:52min) and 257 samples (4 shells, half sphere, 133ms(Cartesian)/114ms(radial)). The conventional rectangular sampling was acquired in 709 samples (6 shells, half sphere, 17:52min) and 257 samples (4 shells, half sphere, 133ms(Cartesian)/114ms(radial)). The conventional rectangular sampling was acquired in 709 samples (6 shells, half sphere, 17:52min) and 257 samples (4 shells, half sphere, 133ms(Cartesian)/114ms(radial)). The conventional rectangular sampling was acquired in 709 samples (6 shells, half sphere, 17:52min) and 257 samples (4 shells, half sphere, 133ms(Cartesian)/114ms(radial)). The conventional rectangular sampling was acquired in 709 samples (6 shells, half sphere, 17:52min) and 257 samples (4 shells, half sphere, 133ms(Cartesian)/114ms(radial)).

Simulations: ODF’s of two crossing fibers (angle 60°) and a water pool (10%) were also simulated as measured with radial (59 radial lines x number of shells) and rectangular (half sphere, number of shells = b-value/1000) sampling and Rician noise added to the data. The simulation results were compared using the normalized RMSE (NRMSE) and the Jensen-Shannon Divergence (JSD) [9] of the Orientation Distribution Functions (ODFs) relative to the ODF’s of the mean of the highest b-value simulation. Confidence intervals [10] were calculated at each SNR and b-value.

Results and Discussion: Figure 1 compares in vivo DSI reconstructions using rectangular and radial q-space sampling. The quantitative anisotropy [11] maps and tractography results of low b-value Radial sampling outperforms the low b-value Cartesian sampling. This observation is also reproduced in the simulation results (Figure 2), which show larger deviations from the simulated ODF as the number of shells drops in Cartesian sampling in comparison to Radial sampling. The simulation results also illustrate the effects of interpolation errors in the conventional Cartesian DSI (Figure 3) as “false” peaks appear in the ODF when the b-value and/or SNR are low. In this setting, the radial DSI approach clearly outperforms its Cartesian counterpart.

Conclusion: Radial q-space sampling for DSI is shown to have an improved angular resolution at lower b-values compared to rectangular q-space sampling for a similar number of samples. These findings, combined with earlier published results [5,6], showing the independence of angular resolution of q-space radius and the avoidance of interpolation errors present when using conventional rectangular q-space sampling, suggest that radial acquisition of q-space can be favorable for DSI.