Optimization of k-Space Undersampled DW PROPELLER using Fast RIGR Algorithm

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Introduction

Diffusion-Weighted (DW) PROPELLER MRI (Periodically Rotated Overlapping ParallEL Lines with Enhanced Reconstruction) is a DW MRI acquisition method that is free from EPI-related artifacts (e.g. image distortion) and has an integrated motion correction scheme [1]. As speed is crucial for obtaining the higher number of required slices in today's DW applications (e.g. DTI), the practicality of DW PROPELLER MRI is hindered from its markedly long scan time [1,2]. One possible strategy for reducing MR scan time is k-space undersampling. Arfanakis and others have reported as much as 50% scan time reduction in PROPELLER MRI using undersampling [2]. Since DW MRI is a "data-sharing" Fourier Imaging method, further scan time reduction may be achieved by improving reconstructed image quality of the undersampled DW PROPELLER data using Fast RIGR (Reduced-encoding Imaging by Generalized-series Reconstruction) algorithm [3]. The purpose of the current study is to investigate the k-space undersampling of the DW PROPELLER MRI with Fast RIGR reconstruction algorithm.

Methods

DW PROPELLER MRI simulation: In the current study, 6 DW images and 1 non-DW image were generated from the digital human brain phantom with the following parameters: b-value = 0 or 900 s/mm^2, TE/TR= 90.4/8000 ms, 6 diagonal DW directions [xy, yz, xz, -(xy), -(yz), -(xz)], 128x128 matrix, FOV= 240mm^2, and 5 skips 0. We considered only a single oblique AC/PC slice for our analysis. These 7 images are referred to as *the base DW set*. To simulate the DW PROPELLER MRI, the k-space data of *the base DW set* were re-sampled in a "rotating blade" fashion. Three sets of the DW PROPELLER data were created: (a) full-sampled DW PROPELLER set (DW_{full}), (b) full-sampled non-DW image and 6 undersampled DW images (DW_{under}), and (c) same as (b), but reconstructed with RIGR algorithm (DW_{RIGR}). When the PROPELLER MRI is "full-sampled", the number of blades collected (B) and the number of k-space lines per blade elements (L) satisfied the Nyquest criteria with $2 \bullet B \bullet L = N \bullet \pi$, where N is the number of sample per k-space line. In our example, N was 128, and to satisfy the Nyquest criteria, B and L were set at 12 and 16, respectively. For undersampled PROPELLER, we considered reductions in both B and L. In case of the B reduction, the reduced number of blades was distributed evenly over the 2π range (Figure 1).

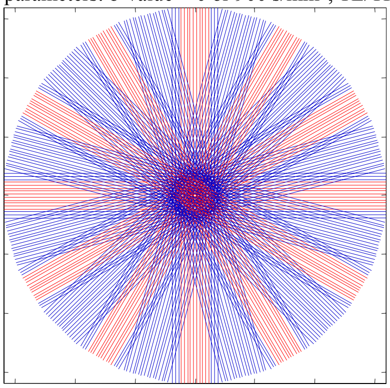

Figure 1: Simulated k-space trajectory for full-sampled (in blue, B=12,L=16) and undersampled (in red, B=6,L=10) PROPELLER MRI

Diffusion Tensor and ALI calculations: To verify the accuracy of the diffusion values in undersampled cases, DW PROPELLER sets were further processed for Diffusion Tensor calculation. The calculated Diffusion Tensor from each DW PROPELLER sets were then quantified using Anisotropy-optimized Lattice Index (ALI) [4]. ALI was used in our study because it considered all 3 of the eigenvalue-eigenvector pairs that diffusion tensor matrix generates for each image voxel. In addition, the ALI incorporates the nearest neighbor pixels into the calculation. The resulting ALI maps from undersampled cases were compared with the ALI map calculated with full-sampled DW PROPELLER data, using 1-way ANOVA.

Scan Time Optimization of the k-space undersampled DW PROPELLER: Assuming that DW PROPELLER MRI was implemented using multi-shot Echo-Train FSE sequences, the total number of encoded k-space lines ($B \bullet L$) determines the total scan time according to Total Scan Time $\propto$ $B \bullet L$. The goal of the optimization was thus to reduce the total k-space encoding lines while maintaining statistically insignificant differences (p>0.05) in the resulting ALI map comparison. For the optimization, the following 3 criteria were met: i) B<12, ii) L<16, and iii) ANOVA p-value from ALI comparison >0.05. Every combination of B and L that fit these criteria were considered.

Results and Discussion

Our simulation shows the benefit of using RIGR in combination with k-space undersampling. Figure 2 demonstrates that for a given amount of undersampled k-space data, the RIGR method is able to improve reconstructed image quality. The DW images showed same blurring effect due to undersampling, but the RIGR method largely eliminated that blurring. The ALI map also shows the improved result from the RIGR method. The result of the scan time optimization is summarized in Table 1. As expected, RIGR method (B=6,L=10) provides a higher percentage reduction compared to the undersampled case (B=5, L=14). Because Total Scan Time is proportional to total number of encoded lines, the undersampled DW PROPELLER combined with Fast RIGR algorithm may reduce the DW PROPELLER image data acquisition time as much as 31.25%.

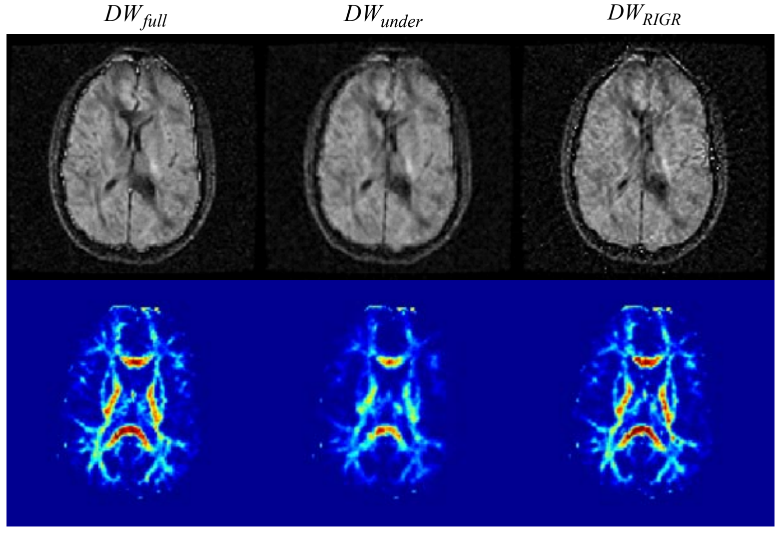

Figure 2: Reconstructed DW PROPELLER images (DWI) and calculated ALI map based on full-sampled (left column, B=12,L=16), under-sampled (mid column, B=6,L=10), and the RIGR method (right column, B=6,L=10). All of the images are normalized across the row for the comparison purpose. Given the same undersampled DW PROPELLER data, the RIGR method improves the image quality in DWIxy with less blurring artifacts. The ALI map calculated from DW_{RIGR} is strikingly similar to the full-sampled case, while the undersampled case seems to underestimate the ALI calculations.

References

1. Pipe et al, MRM, 2002.
2. Arfanakis et al, MRM, 2005.
3. Liang et al, IEEE Trans.Med.Im.,2003.
4. Natsuaki et al., Proc.ISMRM, 2005.

TABLE 1: B and L Optimization Results

DW data	B	L	B · L / fullEnc. (Red. %)	ANOVA p-value
DW_{under}	5	14	70 /192 (36.46%)	0.1386
DW_{RIGR}	6	10	60 /192 (31.25%)	0.1371